ECON INCORPORATED

A PLAN FOR APPLICATION SYSTEM VERIFICATION TESTS

- THE VALUE OF IMPROVED METEOROLOGICAL INFORMATION -

VOLUME I

(NASA-CR-149210) A PLAN FOR APPLICATION SYSTEM VERIFICATION TESTS: THE VALUE OF IMPROVED METEOROLOGICAL INFORMATION, VOLUME 1 Final Report (ECON, Inc., Princeton, N.J.) 168 p HC A08/MF A01 CSCL 04B G3/47

N77-12634

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FINAL

A PLAN FOR APPLICATION SYSTEM VERIFICATION TESTS

- THE VALUE OF IMPROVED METEOROLOGICAL INFORMATION -

VOLUME I

Prepared for

National Aeronautics and Space Administration
Office of Applications
Washington, D.C.

Contract No. NASW 2558

August 31, 1976

ABSTRACT

NASA is currently considering undertaking one or more Application Systems Verification Tests (ASVTs) concerned with demonstrating the practicality and value of improved meteorological forecasts made possible by satellite data and made available on a timely basis to decision makers. This report describes the framework within which the ASVTs can be performed and the economic consequences of improved meteorological information demonstrated. This framework considers the impact of improved information on decision processes, the data needs to demonstrate the economic impact of the improved information, the data availability, the methodology for determining and analyzing the collected data and demonstrating the economic impact of the improved information, and the possible methods of data collection.

Three ASVTs are considered and program outlines and plans are developed for performing experiments to demonstrate the economic consequences of improved meteorological information. The ASVTs are concerned with the citrus crop in Florida, the cotton crop in Mississippi and a group of diverse crops in Oregon. The program outlines and plans include schedules, manpower estimates and funding requirements.

ACKNOWLEDGEMENTS

ECON, Inc. acknowledges the contributions of Joel S. Greenberg, Dr. Ran Bhattacharyya, Peter Stevenson, Celia Drumheller, Dr. Dan Nikodem and Robert Weatherwax who performed the analyses and authored this report. The analyses performed by ECON could not have been accomplished without the close cooperation of National Weather Service and U.S. Department of Agriculture representatives in Florida, Mississippi, Arkansas and Oregon. ECON also was assisted by representatives of the University of Florida, Colorado State University, University of Mississippi and Oregon State University and by numerous farmers, growers and orchardists and their cooperative organizations.

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1. INTRODUCTION

1.1 Purpose of Study

NASA is currently considering undertaking one or more Application Systems Verification Tests (ASVTs) concerned with demonstrating the practicality and value of improved meteorological forecasts made possible by satellite data and made available on a timely basis to decision makers. As part of these considerations, ECON, Inc. was asked to establish and develop the economic tests necessary to show (a) the economic relationships of the operations of the ASVTs to short-term weather variables, and (b) the economic relationships of the effect of improved weather information from current operational weather satellites on the ASVT operations. More specifically, ECON was asked to determine the economic elements and operation factors involved in the ASVTs to permit a further detailed economic analysis of the effects of meteorological satellite information during the actual ASVT demonstration. The ECON activities have therefore been concerned with

(a) the determination of the current decision processes and related economic factors involved in each proposed ASVT,

(b) the establishment of the economic data needs for both current operations and the modified operations that are expected to result from the utilization of the additional and/or improved weather information,

(c) determination of the procedures and methods for obtaining the economic data identified in point (b) above,

(d) establishment of a program outline and plan for the necessary data collection, evaluations and schedules for conduct of the ASVTs,

(e) identification and definition of the necessary interfaces required between the various organizations (i.e.,

Federal agencies, state and local governments and agriculture and professional organizations) which may be involved in the ASVTs, and

(f) an assessment of the energy savings and environmental benefits that may result from changes in procedures, operations and/or policies as a result of the improved weather information.

ECON has therefore set out to develop the framework within which the experiments can be performed and the economic consequences of improved meteorological information demonstrated. This framework considers the impact of improved information on decision processes, the data needs to demonstrate the economic impact of the improved information, the data availability (past, present and future), the methodology for obtaining and analyzing the collected data and demonstrating the economic impact of the improved information, and the possible methods of data collection. The result is a program outline and plan for performing experiments to demonstrate the economic consequences of improved meteorological information.

1.2 Background and Constraints

The ECON analyses were primarily directed in support of demonstration or "NOWCAST" experiments being planned by Colorado State University and University of Florida. Colorado State University is planning demonstration experiments to show the practicality and value of frequent television broadcasts of SMS cloud imagery, radar images, current weather analysis, surface weather information and other weather advisories to specific agriculture user groups. It is anticipated that the SMS cloud imagery, together with the other weather information, will lead to improved scheduling decisions so as to

significantly reduce weather related costs and losses. Colorado State University concluded that the television broadcasts could and should be provided to the agriculture sector in the states of Mississippi and Oregon. The University of Florida is planning a demonstration experiment to show that frost and freeze prediction improvements are possible utilizing operational satellite information and that this information together with timely SMS temperature measurements, can affect Florida citrus grower operations and decisions so as to significantly reduce the cost of frost and freeze protection and crop losses resulting from frost and freeze.

This report is concerned with the formulation of a plan for the performance of the demonstration experiments in a manner such that the economic benefits of the new and/or improved information can be reliably established. It is important to note that, to a large extent, the forecasts and information distribution methods and procedures will proceed independent of the experiment to measure the economic benefits of improved forecasting and/or new information. This has a major impact on the design and conduct of the economic portion of the experiment. Therefore, because of the limited control (from the point of view of the measurement of economic benefits) of the specific information type, format, timing and distribution methods, the economic portion of the experiment (ASVT) must be designed from the point of view of measuring the economic benefits associated with "new information" relative to "old information". Because of the control limitations, the experiment will yield the benefits of improved information without specific regard to the detailed characteristics of the information. In

particular, for example, in the case of the Mississippi cotton crop ASVT, it will be possible to establish the economic benefits of the particular combination of cloud cover images, radar images, meteorological forecast interpretations, etc., being distributed in the particular TV format. It will not be possible to explicitly measure the economic benefits associated specifically with the distribution of the cloud cover images nor with changes in the quantity, quality and timing of the distributed information. It should be noted that in the case of the cotton growers, the National Weather Service (NWS) false alarm and miss statistics are not totally relevant. What is relevant are the cotton growers perceived false alarm and miss statistics which are the result of their evaluation of the NWS forecasts in combination with the TV broadcasts of SMS cloud cover pictures plus meteorologist interpretations.

Within the above basic and important constraint, it is the objective of the experiments to measure the economic benefits which result from the distribution and use of the improved information (content, frequency, accuracy, etc.) and to extrapolate the results. Extrapolation is necessary since some form of sampling is dictated by time, budget and data source constraints. Thus the experiment must be such as to measure the economic benefits associated with a sample and then to provide the information such that the benefit data can be extrapolated to other farmers, ranchers and growers (i.e., the ultimate users of the information) in other geographic locations.

Each of the experiments necessitates the establishment of a control group and a test group and the comparison of the costs and

losses associated with the two groups. The control group consists of a number of cooperating farmers, ranchers and/or growers which undertake business as usual--that is, they do not have access to the improved information. The test group consists of a number of cooperating farmers, ranchers and/or growers which have improved information available to them. The purpose of the experiment is to measure and thence compare the costs and losses associated with these two groups. A number of basic problems are immediately evident: (a) What data should and could be collected? (b) What is the accuracy of the data? (c) What should be the populations of the control and test groups? (d) What level of confidence should be, and can realistically be, the goal of the experiment? (e) How should the control and test groups be formed (i.e., the sampling strategy)? (f) Over what duration should data be collected?

1.3 Approach

Three related, though basically different, experiments as mentioned previously, are herein considered. It is important to understand the basic differences between these experiements. Consider first the ASVT involving Colorado State University. This ASVT, actually consisting of two possible experiments (Mississippi and Oregon), requires the determination of the economic benefits of additional information (the TV pictures of cloud cover and radar data and meteorologist interpretations)--that is, the information is in addition to the NWS forecasts available to the cotton (and possibly other crops) growers in Mississippi and farmers and orchardists in Oregon. In order to measure the economic benefits, it is necessary to establish a control group

and a test group. In the case of the Mississippi experiment, the control group must consist of farmers which do not receive the new information. Since all farmers in Mississippi will have available the TV information (to be distributed via the state educational TV network), the following several options are possible, (a) the control group may consist of farmers in Arkansas and/or Louisiana which produce similar crops, have similar growing and weather conditions, employ similar farming practices, etc., and data collected during the same time period as that of the test group in Mississippi, (b) the control group may consist of farmers in Mississippi prior to the distribution of the new information, (c) the control group may consist of farmers in Mississippi which provide historical cost, loss, activity and weather forecast and actual occurrence data, and (d) a combination of (a), (b) and (c). In no case can a control group be established in Mississippi which provides data concurrently with the test group. Because of this fact, the response to the new information will have to be observed in different geographic areas and/or in different time periods. Since different weather occurrences and different forecast capabilities will probably exist between the control group and the test group, it is necessary to perform an adjustment to the basic data which biases out these differences. Again, the reason for this is that in the Mississippi experiment it is desired to ascertain the economic benefits of the TV distributed information directly to the farmers and not the benefits arising from differences in the NWS forecast capabilities.

The current concept of the Florida experiment is to provide the SMS temperature data and related forecasts to the NWS which, in

turn, will utilize this, along with other information, in improving their forecasts to the citrus growers. In this case, since the satellite data will be used directly by the NWS and will not (at least initially) be provided directly to the growers, it is desired to measure the economic benefits resulting from improvements in the NWS frost and freeze forecasts which result from the use of satellite measured temperature data.

The question of the control group arises again. In the case of the Florida experiment it does not seem possible to establish a control group by geographic segmentation. All of the citrus growers in Florida receive the current and will receive the improved NWS forecasts. Therefore, the control group will have to be based upon either or both historical data and data which could be collected during the 1976-77 frost season (assuming, of course, that the SMS temperature measurements and University of Florida forecasts are not introduced during this frost season). Indications are that a limited amount of historical data may be available. It should be noted that data preceding the rapid rise in fossil fuel prices is suspect since grower protection decisions are influenced significantly by their fuel cost.

The Oregon experiment is a combination of the information distribution technique of the Mississippi experiment and the data gathering technique of the Florida experiment. The same type of information as that discussed for the Mississippi experiment will be distributed to the farmers and orchardists in Oregon via television. The problem of establishing a control group is similar to that of the Florida experiment. Since the TV signal will be available to most farmers and

orchardists, as in the case of the Florida control group, a control group can only be established by using historical data and/or collecting data during growing seasons prior to the introduction of the new information. The major difference between the Oregon and the other two experiments is the number of different crops and divergence of farming practices in Oregon relative to Mississippi and Florida. This contributes significantly to the complexity of performing an experiment to measure the economic benefits of the new information to the Oregon farmers and orchardists.

In summary, three experiments are considered in the following pages, namely (1) an experiment to demonstrate the use of SMS temperature measurements in citrus crop production and to measure the resulting economic benefits (the Florida Citrus Industry ASVT), (2) an experiment to demonstrate the utility of television dissemination of SMS cloud cover pictures and other data to cotton and other farmers in Mississippi and to measure the resulting economic benefits (the Mississippi Cotton Growing ASVT), and (3) an experiment to demonstrate the utility of television dissemination of SMS cloud cover pictures and other data to farmers and orchardists in Oregon and to measure the resulting economic benefits (the Oregon Mixed Crop ASVT). These three experiments are discussed in Sections 4, 5 and 6 of this report, respectively. Each of these sections deals with the development of a plan for performing a specific experiment. Section 7 deals with a recommended plan for performing the three experiments in a time phased sequence making allowances for anticipated funding constraints and manpower scheduling. Sections 2 and 3 present general background material

on concepts of economic benefits and the design of experiments, respectively.

2. THE CONCEPT OF ECONOMIC BENEFITS AND SOCIAL WELFARE

Though the ASVT experiments will measure the cost savings and loss reductions realized by the farmers due to the SMS-improved weather forecasts, these savings will not necessarily constitute a net gain in social welfare. If one group's gain is only made possible by another's loss, the net benefit to society is zero. The purpose of this chapter is to present and explain techniques for measuring changes in net social welfare. The most common method of welfare evaluation recognizes two distinct classes within society for a given commodity, the producers and consumers. The consumers' case will be presented first.

2.1 Consumers' Surplus

One of the basic postulates of economics states that for every consumer there exists a relationship between price and quantity for each commodity observed by the consumer. For most consumers and for most commodities, this relationship will be inverse. The more satiated the consumer becomes from each successive unit of the good purchased, the less he is willing to pay for the next unit. Conversely, the consumer is willing to pay his highest unit price for the first unit of the good purchased. Though the reasoning here is intuitive, it can be expressed quantitatively by assigning a decreasing number of "utils" to each successive unit of the good. The greater the number of "utils", the more utility the consumer derives. Though the consumer would increase his total utility by purchasing the nth unit of the commodity, he will pay less for it since he experiences a decrease in marginal

utility. Given that there exists a correspondence between utils and dollars, the concept of consumer's surplus can now be discussed. (Note the apostrophe after the r, indicating the surplus of a single consumer.) Consumer surplus is defined as the maximum sum of money a consumer would be willing to pay for a given amount of the good less the amount he actually pays. If consumer A were asked how much he would be willing to pay for one pencil, then two pencils and so forth to n pencils, his responses might indicate the demand relationship found in Figure 2.1. If the market price for each pencil were 20 cents, consumer A would find himself with a surplus which he would have been willing to pay for but in fact did not.

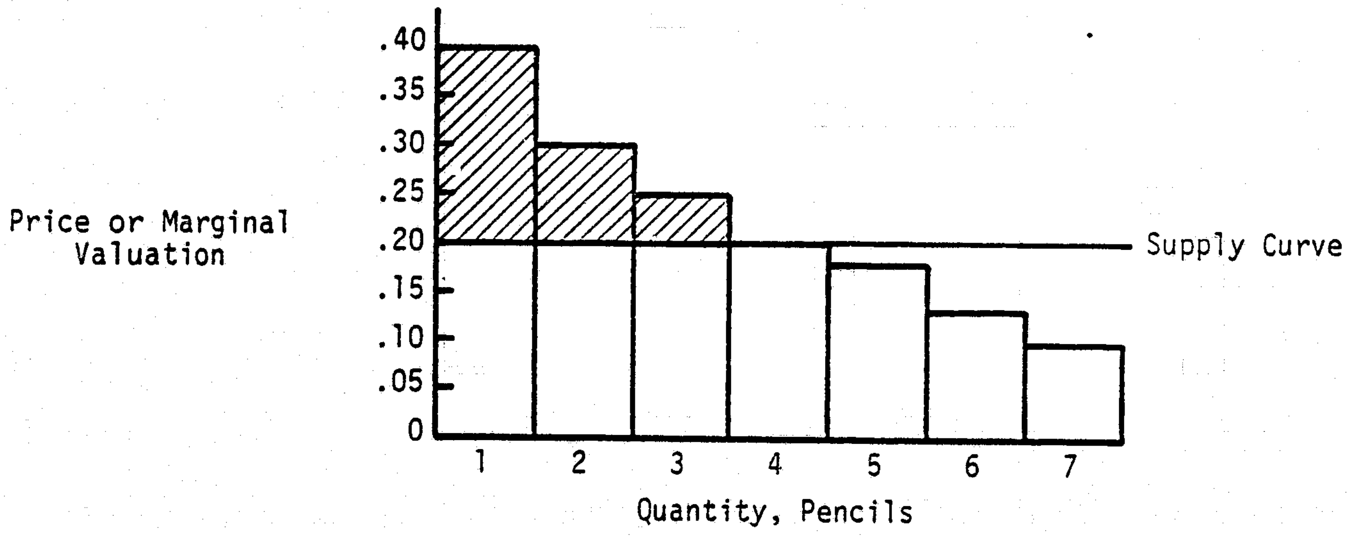


Figure 2.1 Consumer's Surplus

The shaded area of Figure 2.1 represents the surplus the consumer realizes. It should be noted that though the market price is the independent variable to the analysis, it is shown on the vertical axis in keeping with the standard economic presentation.

The use of this welfare measure in applied work usually relies on several assumptions. First, it is assumed that there exists perfect product divisibility so that the demand curve becomes continuous. Secondly, if the scope of the analysis is over all consumers, it is necessary to derive an aggregate demand function for society. The aggregate demand schedule which can be derived econometrically is assumed to be the summation of each and every individual demand curve. The analysis at the aggregate level is termed consumers' surplus (note change in apostrophe). Finally, measurement of consumers' surplus is usually accomplished under a "partial equilibrium" framework, in which prices are studied one at a time, in isolation. Other prices may be introduced into the analysis to help fix the shapes and positions of demand and supply curves but, once admitted, these other prices are held constant by assumption.

Given that there already exists a market for a given good, the relevant social welfare or benefit measurement is the <u>change</u> in consumers' surplus brought about by a decrease in the price of the studied commodity. Though the price of any commodity is bound to change frequently, the economist attempts to either predict or empirically estimate the change in price that is due to a particular benefit producing innovation.

2.2 Producer's Surplus

In the preceding section, the notion of the demand curve was discussed along with an explanation of marginal utility. Since both the market price and quantity supplied of a good are determined by the intersection of the supply and demand schedules, it is now necessary to cover the elements of supply. The supply schedule shows the relationship between market prices and the amounts of a good that producers are willing to supply. For most producers, the supply schedule will be upsloping. For example, at a higher price of wheat, the farmer will take acreage out of corn cultivation and put it into wheat. In addition, the farmer can now afford the cost of more fertilizer, more labor, more machinery and can even afford to grow extra wheat on poorer land. All this tends to increase output at higher prices. Furthermore, in the same way that the consumer experienced a decrease in marginal utility as he consumed each successive unit, the producer experiences an increase in <u>marginal cost</u> as he produces each successive unit. It is because each participant in the market attempts to either maximize his marginal utility or minimize his marginal cost that the supply and demand schedules find a point of intersection and hence transactions take place.

Having established that competitive producers will supply goods and services at prices dictated by their marginal cost or supply schedule, it is now possible to give a simple definition of producer's surplus. The producer's surplus is simply the value of the maximum amount of a good or service a producer would be willing to produce less the cost of what he actually produces. Figure 2.2 illustrates

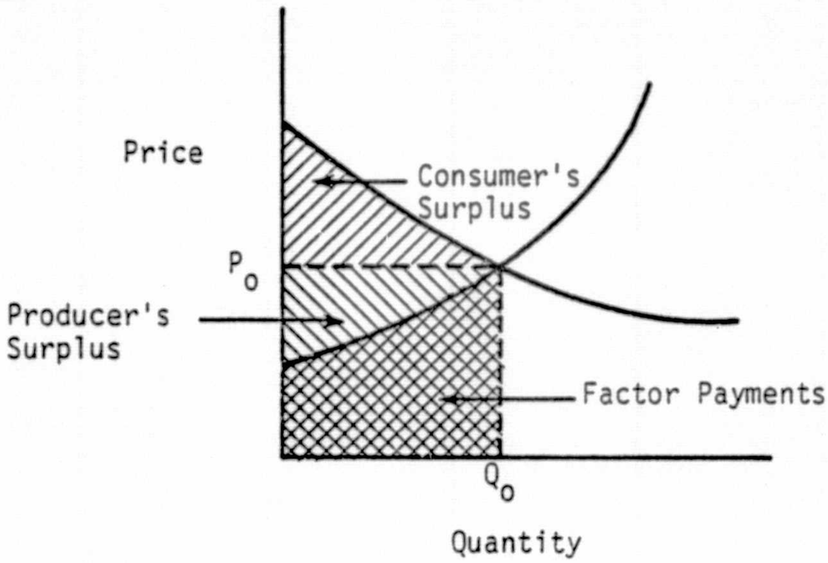


Figure 2.2 Illustration of Consumer's and Producer's Surplus

both the consumer's surplus discussed before and producer's surplus. The cross-hatched area of factor payments represents the minimum amount the producer must pay to the factors of production, i.e., land, labor, capital and his own entrepreneurial skill, to produce Q_o units.

Many of the same restrictions and assumptions necessary in the practical measurement of consumers' surplus are also needed here. First, Figure 2.2 assumed perfect product divisibility for both the demand and supply schedules. Secondly, the analysis again takes place in partial equilibrium where price changes are studied in isolation. Finally and most importantly to the derivation of producers' surplus (note change in apostrophe), each firm's individual supply curve is summed horizontally to arrive at the aggregate or industry supply curve.

The slope of the aggregate supply curve depends upon the degree of competition within the industry. Since the slope of the aggregate supply curve will to a large degree dictate the amount of producers'

surplus present for a given commodity, it is important to study the competitiveness of the industry producing the commodity.

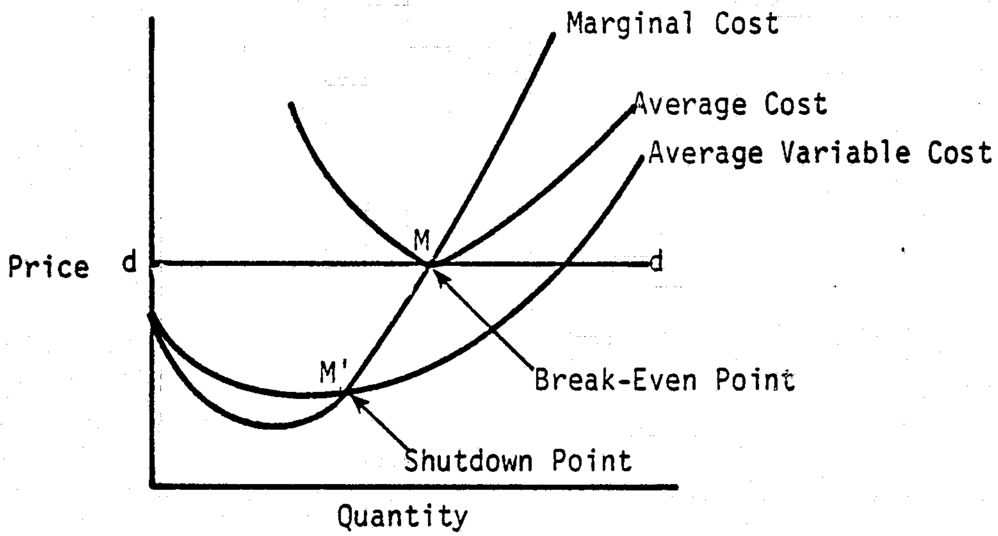


Figure 2.3 Shutdown and Break-Even Points for a Single Firm in Perfect Competition

A firm in perfect competition, for example, will attempt to maximize profits by moving up its marginal cost curve above its break-even point, as shown in Figure 2.3. The break-even point is at M where dd is tangent to AC (Average Cost) and AC is at its minimum. The short-run shut-down point is similarly at the bottom of the AVC (Average Variable Cost) curve.* Since a perfect competitor is too small and unimportant to affect the market price, he is a "price taker" who can sell all he wishes at the ruling market price. Hence the perfect competitor faces a horizontal demand curve for his product, dd as shown

*If TC = FC + VC; where TC = total cost, FC = fixed cost and VC = variable cost; (1) AC = TC/q where AC = average cost and q = units of output; (2) AVC = VC/q and (3) MC = $\Delta TC/\Delta q$.

in Figure 2.3. Even if the firm is temporarily able to sell above the break-even point (dd shifts upward) and move up its marginal cost curve, other firms will enter the market and force the firm to either sell again at point M (break-even point) or face the prospect of no sales. Hence in the long run both the firm's supply curve and the industry supply curve is perfectly horizontal. Importantly, if the industry is perfectly competitive, producers' surplus will not exist in the long run (See Figure 2.1).

For other forms of competition, ranging from anything which is not perfectly competitive, through oligopoly and up to monopoly, firms will have some degree of influence over aggregate supply. As a result, firms will be able to operate at a point on their marginal cost curve above the break-even point and the summation of the individual marginal cost curves will result in an upward sloping aggregate supply curve. Consequently, if the industry is imperfectly competitive, producers' surplus will exist.

2.3 The Concept of Benefits as Applied to the ASVT Experiments

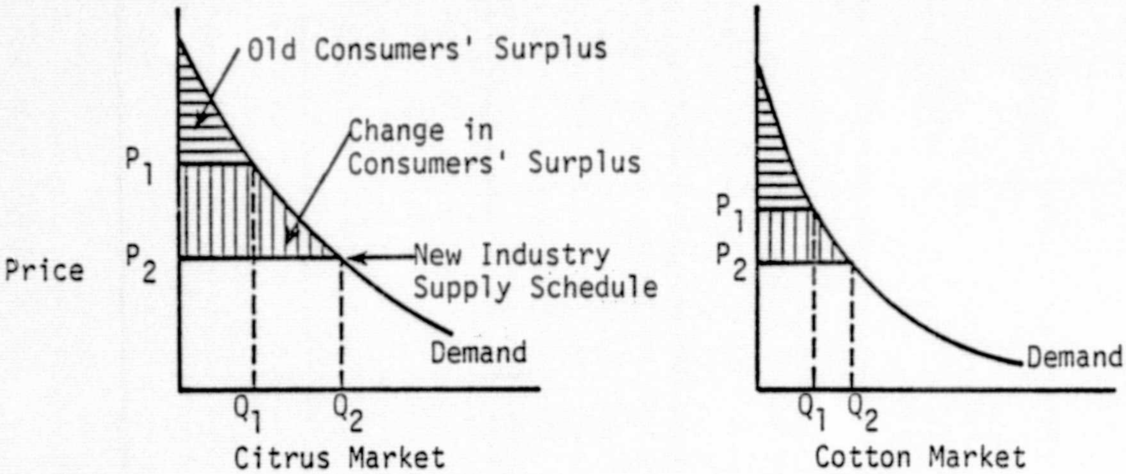
It is hoped that the SMS-improved forecasts will allow farmers to reduce their weather-related costs (including losses). The citrus grower, for example, by knowing that the temperature will increase above freezing at 3 a.m., will be able to dismiss his labor crew and shut down his heaters and wind machines, thereby reducing his labor and fuel costs. The effect of reducing production costs is to simply allow the farmer to produce more for less cost, and in terms of the above discussion, his individual marginal cost schedule shifts downward and to the right.

If the farmers were in perfect competition by commodity, the effect of SMS would be to shift the horizontal industry supply curves downward so as to arrive at a new and lower equilibrium market price for each commodity. The resultant change in consumers' surplus would be the benefit to society due to SMS. Figure 2.4 illustrates this concept.

If the farmers were in an imperfectly competitive industry, the horizontal summation of each marginal cost curve would produce an upward sloping industry supply and both the consumers' and producers' would benefit. Figure 2.5 illustrates this concept.

The new consumers' surplus area (DBP_2) includes area (P_1ABP_2) which represents the change in consumers' surplus (CS) and is the benefit of the P_1 to P_2 price change. Evaluation of (P_2BC) - (P_1AP_2) gives the correct change in producers' surplus. In order to calculate the net change in total social welfare (TSW), the CS and PS associated with P_1 are summed and subtracted from the sum of CS and PS associated with P_2. Using the above notation, this becomes $TSW = PS + CS$ and $\Delta TSW = (DBC) - (DAP_2) = P_2ABC$.

It has been assumed throughout that all the resources which are saved through the use of the SMS and related information are automatically put to their next most advantageous use. In application of this assumption to the specific problems of the ASVT, it can be seen that this may not always hold true. With the physical resources such as fuel or the chemicals used in pesticide production, this assumption seems reasonable, however, the use of labor is somewhat less flexible. For instance, in citrus frost protection (the most labor



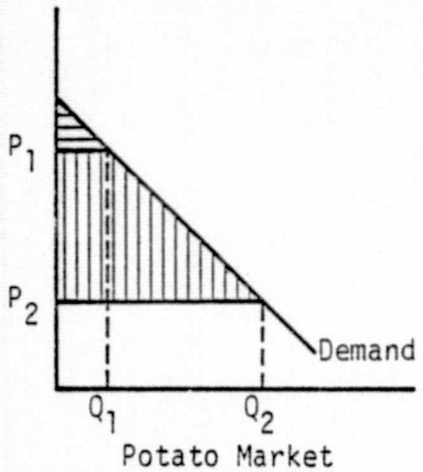


Figure 2.4 Illustration of Change in Consumers' Surplus if the Citrus, Cotton and Potato Markets Were Perfectly Competitive

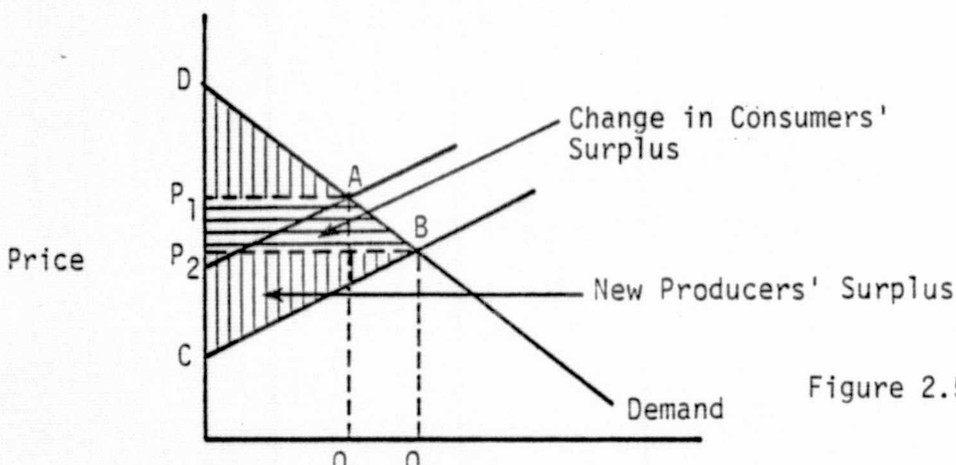


Figure 2.5 Illustration of Change in Producers' and Consumers' Surplus

intensive of all the operations under study) the SMS data may allow the grower to turn off his heaters and wind machines a few hours earlier. Thus, the grower would be able to send his crew home earlier and save the labor cost of those few early morning hours. The worker who was sent home in most cases could not have known the evening before that he would have those hours free. Without notice, it is unlikely that he would be able to switch for those few hours into his next most productive role. Therefore in many if not most cases, he would be forced to take those hours in leisure time and even though many economists will claim that leisure time has value, in such a situation where the acceptance of leisure time is forced rather than chosen the value may be very slight. The result will be that the worker in an attempt to at least maintain his level of income will seek a higher hourly wage rate to compensate for the reduced number of hours worked. This will in time have the effect of shifting the supply curve back upwards and to the left, partially offsetting the gains initially produced by SMS. This change has been added to Figure 2.5 and the new situation appears in Figure 2.6. The result is the reduction of consumers' surplus from P_2 BD to P_3ED and the change in producers' surplus from P_2BC to P_3EF.

An assumption that will be made during the conduct of the ASVT is that the demand for the agricultural products is perfectly inelastic. (Elasticity of demand being defined as the inverse of the percentage change in quantity for a given percentage change in price.) This means that a change in price will not affect the quantity demanded. This is illustrated in Figure 2.7.

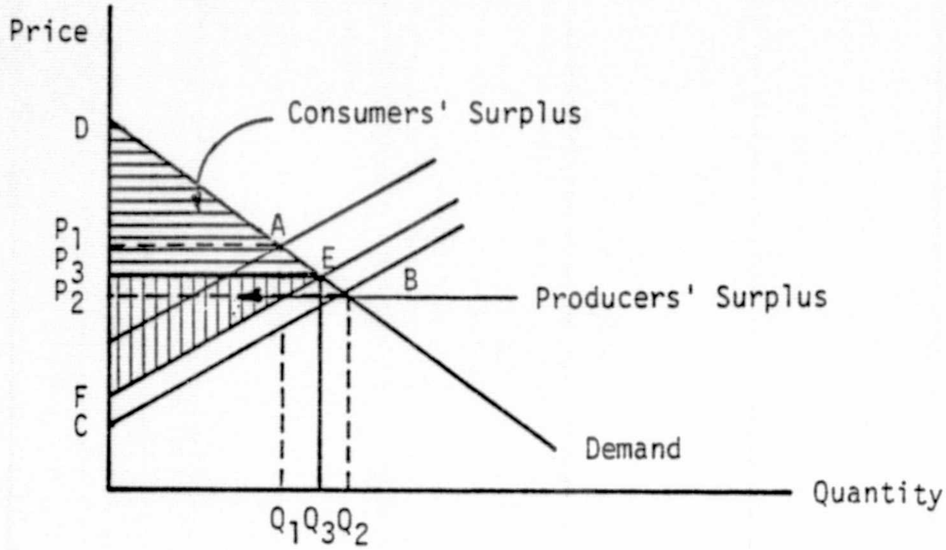


Figure 2.6 Change in Consumers' Surplus and Producers' Surplus if Conserved Resources are not Fully Used

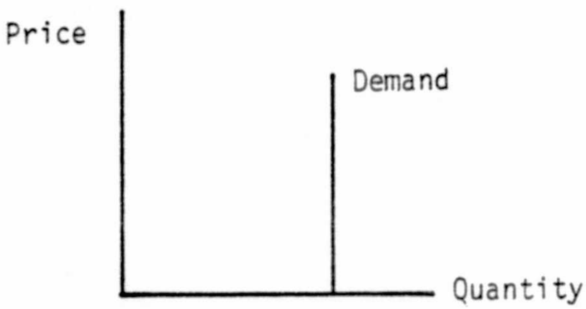


Figure 2.7 Perfectly Inelastic Demand Curve

This assumption allows an evaluation to be made of the percentage of the crop saved by more accurate protection methods at the current market value rather than at some lesser value which would be required with the traditional downward sloping demand curve. Since many agricultural markets seem to be extremely (though not perfectly) inelastic, it is thought that this assumption will not significantly affect the results. In certain cases (for example, the economic impact of improved knowledge of statewide temperatures and its effect on marketing decisions) the inelastic demand assumption will not be invoked.

When measuring the cost savings during the conduct of the ASVT, the assumption of perfect competition will be added to that of perfect inelasticity. Figure 2.8 illustrates the resulting measurement as a change in consumers' surplus.

Only when spot and futures prices of the goods produced and other such market information is added to the economic analysis will these assumptions be removed and market effects considered. Thus the final model of the citrus industry will be aimed at measuring the net benefit of new and/or improved information to an industry with upward sloping supply curves and downward sloping demand, as illustrated in Figure 2.9.

The change in consumers' surplus is from P_1AC to P_2BC and producers' surplus changes from P_1AD to P_2BC. The net benefit then is the cross-hatched area ABED (note the area Q_1Q_2BF is considered a function of the change in market quantity and neither a change in consumers' nor producers' surplus).

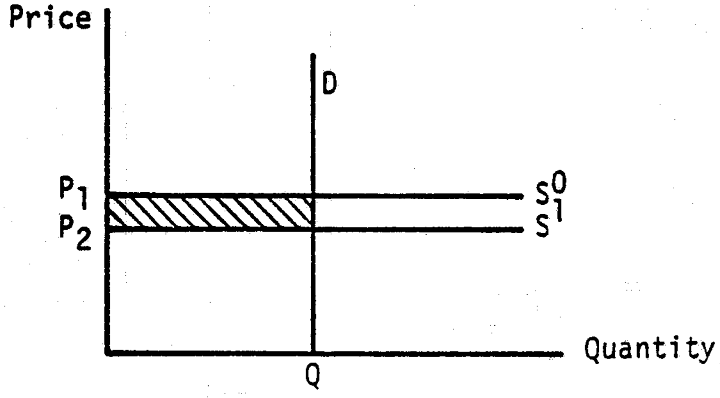


Figure 2.8 Change in Consumers' Surplus Assuming Perfectly Inelastic Demand and Perfectly Competitive Markets

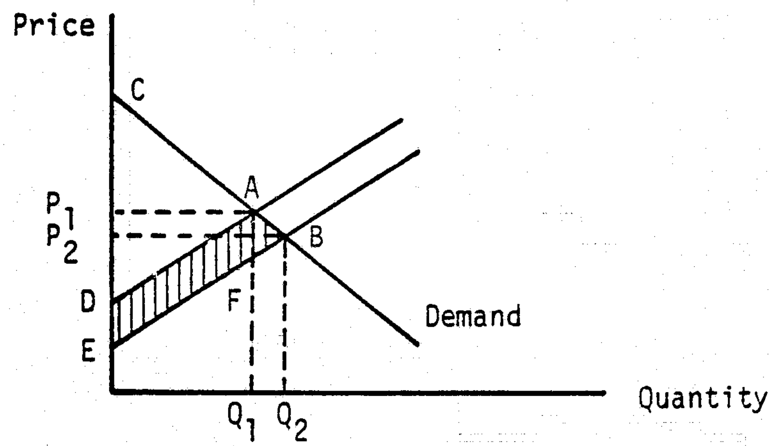


Figure 2.9 Producers' and Consumers' Surplus Changes Under Imperfect Competition and Less Than Perfect Inelasticity of Demand

3. DESIGN OF AN EXPERIMENT

An experiment essentially consists of measuring the attributes of an "action" and the "consequences" with the purpose of demonstrating whether a relationship of causality exists between the two. For the case at hand, the "action" consists of providing improved meteorological information to users like the citrus growers in Florida, the cotton growers in Mississippi and the farmers and orchardists in Oregon. The "consequences" are the economic benefits resulting from the use of the improved meteorological information. Ultimately, the demonstrated results of the experiment will be extrapolated over a broad range of relevant crops and geographic areas.

The scope of the application system verification tests has already been introduced as has the concept of economic benefits. In order to demonstrate the economic benefits associated with improved meteorological information, it becomes necessary to measure the incremental benefits that accrue to the users of the improved information relative to those who conduct very similar activities but do not receive the improved information. This is essentially the control group/test group concept of statistics. By definition, the control group comprises those users that do not receive the improved information, and the test group consists of users that receive the improved information. These two groups need to be carefully selected and should resemble each other as closely as possible, except for the availability of improved information.

The number of users consitituting the two groups is usually restricted by both practical as well as economic considerations. It cannot be expected that all users will be cooperative. Further, it may not be economically feasible to accommodate all cooperative users in case that number is inconveniently large. Hence, there is a need for an efficient sampling scheme. The sampled population should be small enough to make the experiment economically feasible, and yet large enough to guarantee the statistical significance of the results. Different users in the sample population may respond to the experiment with different levels of promptness and elaborateness. This adds to the complexity of the experimental design.

Finally, the scheme of extrapolation of the experimental results over a broader population has to be carefully developed. As an example, the results obtained with reference to the citrus growers in Florida may not apply in the same proportion to the citrus growers in California due to some inherent differences in farming practices, unit costs, weather conditions, etc. Thus, various details have to be accommodated in the normalization scheme in order to make the extrapolation meaningful. The various concepts introduced in this section are expounded in the following pages.

3.1 Control Group/Test Group Concept

Ideally, the population defined as the control group and that defined as the test group should be identical in every respect except that the improved meteorological information is made available to the test group while the control group is denied this information. In practice, it is difficult to realize this ideal situation because

no two users are identical. However, there are several ways in which this ideal situation may be approximated. One is a scheme of concurrent data collection over two similar groups in two geographically similar locations--one receiving the improved information and the other not receiving the improved information. A second approach is to consider only one group of users who serve as both the test and control groups. As the test group, data are collected only subsequent to the availability of the improved meteorological information. The control group is based upon historical information covering a period prior to the introduction of the improved meteorological information. A variation of the second approach would be to concentrate on one group and start collecting data in the immediate future before improved meteorological information is made available. This, of course, assumes that there will be enough lead time before the dissemination of improved information can be realized so that sufficient data can be gathered from the control group. With the introduction of improved information at some future date, this control group becomes the test group.

All of the three schemes described above have their limitations. In the first scheme, variations in local characteristics like soil types, farming practices, etc., may pose a problem. Moreover, infiltration of information between the two groups due to their geographical vicinity may introduce errors. In the other two schemes, the presence of various time-varying factors may lead to an unfair comparison between the data collected at different points in time. The year-to-year weather variation is a time-varying factor. Another

example is the variation in farming practices due to changes in price as well as technologies. For example, if the price of fuel is negligible compared to the revenue that may be lost due to the occurrence of a frost, a citrus grower may decide to heat his grove at the slightest indication of a probable occurrence of frost. On the other hand, if the price of fuel is so high that heating the grove is more expensive than the loss that may occur due to frost, the grower may decide never to heat his grove. The comparison between two such situations is unfair because under such circumstances the variation in earned revenue is not primarily related to the quality of the weather forecast. Under the control/test schemes presented above, in order to ensure a fair comparison between the control group and the test group, it is necessary to normalize the various costs to bring them to a common denominator. A detailed scheme of normalization is presented in Appendix B.

In the case of the cotton growing industry, the entire state of Mississippi will receive the improved information distributed via the education TV network. Thus, with the initiation of the distribution of the improved information, there will be no growers in Mississippi who can be denied access to the information. However, it is likely that this information cannot be made available before January 1978. Hence, assuming that data collection gets started by the end of 1976, it is possible to collect data during one or two growing seasons before the improved information is available. This data can provide the control group representation. However, if it appears that there is a wide variation in the values of the above mentioned time-varying

factors over these years, it may be necessary to form a control group with cotton growers in Louisiana or Arkansas and collect concurrent data from the test group and the control group after the improved meteorological information is available. If, on the other hand, there are no significant time-varying factors, the data collected in Mississippi over the next two years become crucial because this data, in turn, may obviate the need for a separate control group in Louisiana or Arkansas.

For the citrus industry in Florida, the situation is somewhat different. There are no neighboring states with any significant citrus growing industry. The only other major citrus growing state is California which is weatherwise significantly different from Florida. Hence, with the whole state of Florida receiving the improved frost forecasts, it is not possible to select a control group to monitor concurrently with the test group. The control data can be obtained in this case from the limited historical data maintained by Florida citrus growers and/or from the citrus growers in the immediate future (i.e., 1976-77 frost season) prior to the dissemination of the improved frost forecasting information.

3.2 Sampling and Statistical Significance

With the concept of the control group and test group having been introduced in the previous section, it becomes necessary to determine how the actual formation of these groups can be realized. The immediate question to consider is: How many users should be selected for each group and what criteria should be used for their selection? To start with, it cannot be expected that all users will be equally

cooperative. Those that are absolutely uncooperative obviously drop out from the scope of the experiment. However, the initial surveys that have been conducted indicate that the number of users who are expected to cooperate constitute a fairly large group. The degree of cooperation will of course vary from user to user. Some may respond once a month. Others may be prepared to respond more frequently. To accommodate all the users may make the experiment too elaborate, time consuming and expensive. Hence, the need for an efficient sampling scheme. If the population is perfectly homogeneous, sampling becomes a trivial task. This happens to be the case when a few drops of blood of a patient are examined for diagnostic purposes, the underlying assumption being that one drop of blood is the same as any other drop belonging to the same patient. But when the population is far from uniform, as is the case in this experiment, the sampling scheme becomes critical. The sample should be a true representation of the population such that the results inferred from the sample are unbiased. Further, the results should be statistically significant in the sense that if the experiment is repeated with another good set of samples, the conclusions should not be drastically different. This calls for a clear understanding of what is meant by bias and statistical significance.

Let s be a sample from the total population of users selected for the experiment according to some sampling scheme. Let b represent the economic benefits measured by the experiment for this sample population. This value of b is then extrapolated according to some formula to a value of $\overline{B}$ which is the estimate of benefits corresponding to the

entire population from which the sample s is selected. It should be noted that $\overline{B}$ is only an estimate of B which is the true value of the benefits realized by the total user population. It cannot be expected that the value of $\overline{B}$ will, in general, be mathematically equal to B. As a matter of fact, the value of $\overline{B}$ depends on the particular sample selected. If another experiment is performed with another sample population selected by the same sampling scheme, the value of b will, in all probability, be different. Consequently, the value of $\overline{B}$ will be different. Thus, $\overline{B}$ is a random variable associated with a probability distribution. In essence, this probability distribution is the plot of all possible values of $\overline{B}$ corresponding to all possible samples that can be collected from the total population in accordance with the specified sampling scheme. If the mean value of this distribution of $\overline{B}$ happens to be equal to B, the estimate is defined as unbiased. An unbiased estimate does not imply that the value of the estimate $\overline{B}$ computed from any one experiment will necessarily be equal to the true value of the benefit B. To elucidate this concept, consider the throw of an unbiased die. Since all the six faces are equally probable to show, the mean number of dots computed over an infinite number of throws is the average of 1, 2, 3, 4, 5 and 6, which is equal to 3.5. If out of the population of infinite throws, a sample of ten throws is selected, the average number of dots computed over those ten throws will not necessarily be equal to 3.5. As a matter of fact, the average value will depend on which ten throws are selected as a sample. But if the average over ten throws is plotted for all possible groups of ten throws, the mean of those averages will be equal to 3.5.

One of the requirements for the experiment to be meaningful is that the benefit estimate $\overline{B}$ obtained from the experiment should be a fairly accurate representation of the actual value B of the benefits. As is discussed earlier, an unbiased estimate does not necessarily guarantee that, though it certainly helps. What is required is to make sure that the different feasible values of $\overline{B}$ remain close to B as far as possible. In other words, the variance (i.e., the spread of the probability density function of $\overline{B}$) should be small and the mean value of $\overline{B}$ should be B. Thus, in order to guarantee a meaningful result of the experiment, one should see that: (1) the estimate of benefit is unbiased, and (2) the variance of the benefit estimate is small.

The concept of the unbiased estimate has already been elucidated with the example of the dice throw. The concept of the variance of the estimate will now be presented with reference to the same example. Consider a sample consisting of only one throw of the die. The outcome can be any one of the six possibilities. In other words, the outcome is uniformly distributed over the integers from 1 to 6. Now consider a sample consisting of ten throws. In order for the sample average to be equal to 1, it is necessary that the outcome of each of the ten throws is 1. This is possible, but its probability is only $(1/6)^{10}$ which is a very small number. Similarly, the probability of obtaining 6 as the sample average is also $(1/6)^{10}$. For all practical purposes, one would expect that if a die is thrown ten times and the average of the ten outcomes is calculated, it will more probably be close to 3.5 (the true mean) rather than be one of the extreme values of 1 or 6. This could not have been said when the sample consisted of

only one throw because all the integers from 1 to 6 were equally probable. Thus, with the increase of sample points, the variance of the estimate tends to decrease. This indicates that the larger the sample size, the more confidence one can have in the estimate. Exactly how large the sample size should be is to be determined from considerations of economic and practical feasibilities.

There is yet another consideration that influences the confidence that can be attributed to the estimate--especially in the case when the population is heterogeneous. Suppose a population consists of 5 men and 5 women. The respective heights of the men are 5'10", 5'11", 6', 6'1" and 6'2". The respective heights of the women are 5'2", 5'3", 5'4", 5'5" and 5'6". Suppose the objective is to estimate the mean height of the population from a limited sample of the total population. It is obvious that any sampling scheme that suggests to exclude the men (or the women) from the sample is bound to yield incorrect results. To obtain meaningful results, the population has to be stratified into the two classes, and then representative samples collected from each class. How many sample points should be collected from each class depends on two factors: (1) the total number of sample points allowed in the experiment, and (2) the range of heights in each class. In this particular example, the range is the same for both the classes, viz 4". But if the heights of men were believed to vary over a wider range than that of the women, it would have to be recommended that more men be included in the sample than women to adequately represent their wider range. The same idea carries over to the experiment at hand.

The population of potential users of improved information is heterogeneous due to a number of reasons. First of all, there may be a systematic difference in weather patterns. For example, among the citrus growers in Florida those in the valley areas and those in higher altitudes will have a difference in temperature patterns. Vicinity of a large water mass such as a lake will introduce a variation. Latitude is yet another variant. Secondly, there may be a difference in forecast quality. This may be due to the fact that different forecasters are responsible for detailed forecasts at the local level. Also, due to some details in geographical characteristics, it may be easier to make a forecast for one local area than for another. Thirdly, there may be variations in farming practices among users due to the volume and nature of business. A large operation like that of Minute Maid, for example, may not be interested in protecting against frost if it finds that it is more economical to make frozen orange juice out of oranges slightly damaged by frost than to save the oranges from frost damage by heating the groves. A small grower, on the other hand, may find that heating the groves is more economical than suffering the loss due to frost. In the case of cotton growers in Mississippi, if it is observed that the comparatively large operations use aerial sprays while the smaller operations use ground spraying, it has to be recognized that the weather sensitivity of these two operations may be significantly different from one another. These examples are intended to elucidate some of the variations of farming practices within a population of users.

The three dimensions of heterogeneity in the population mentioned above (viz weather occurrence, weather forecast and farming practices) should provide the guidelines for stratifying the population before representative samples can be selected from each stratum (note that in the example of average height measurement in a mixed population of men and women, the population should be divided into two strata).

In order to determine how many sample points need be selected from each stratum, it must be determined if the total number of users belonging to all the strata who are willing to cooperate with the experiment constitute a population too large to include in the experiment from a realistic and economical standpoint. If the answer is in the negative, all the available users should be accommodated in the experiment. If the answer is in the affirmative, a stratified sampling scheme has to be adopted. One such scheme is developed in detail in Appendix A. It should be kept in mind that a certain percentage of the selected users may drop out as the experiment proceeds. Thus, it may be wise to build in an allowance factor.

4. CITRUS INDUSTRY ASVT (FLORIDA)

4.1 Objective

The objective of the Florida Citrus Industry ASVT is to demonstrate the impact that satellite derived temperature data can have on citrus crop management in the State of Florida. The University of Florida is planning a demonstration experiment to show that frost and freeze prediction improvements are possible utilizing operational satellite information and that this information together with timely Synchronous Meteorological Satellite (SMS) temperature measurements, can effect Florida citrus grower operations and decisions so as to significantly reduce the cost of frost and freeze protection and crop losses resulting from frost and freeze. Therefore the Florida Citrus Industry ASVT has as a further objective the conduct of an experiment which will monitor citrus grower decisions, actions, costs and losses, and meteorological forecasts and actual events and allow the economic benefits of satellite derived temperature data and related temperature forecasts to be ascertained.

It is the purpose of this Section to establish a plan for the detailed design and conduct of an experiment which will yield measurements of the economic benefits which may be derived from satellite temperature measurements.

4.2 The Florida Citrus Industry

4.2.1 Geographical Distribution and Production Value of Citrus Producing Regions

The areas in the United States which are most suitable for

citrus production are located predominantly in the subtropical regions of the southeast and southwest. These regions have climates which are relatively free from freezing temperature and wind hazards. Florida is the major producing region with approximately 65 to 70 percent of the total U.S. production. The second largest citrus growing region is southern California. Additional areas having important citrus crop production are found in Texas and Arizona (Figure 4.1).

The general term citrus includes early, midseason and late (Valencia) oranges, grapefruits, tangerines, tangelos and temples. The major products are oranges and grapefruits. The rest are normally referred to as specialty fruit. Lemons and limes are grown in the most southern part of Florida where low temperatures rarely occur.

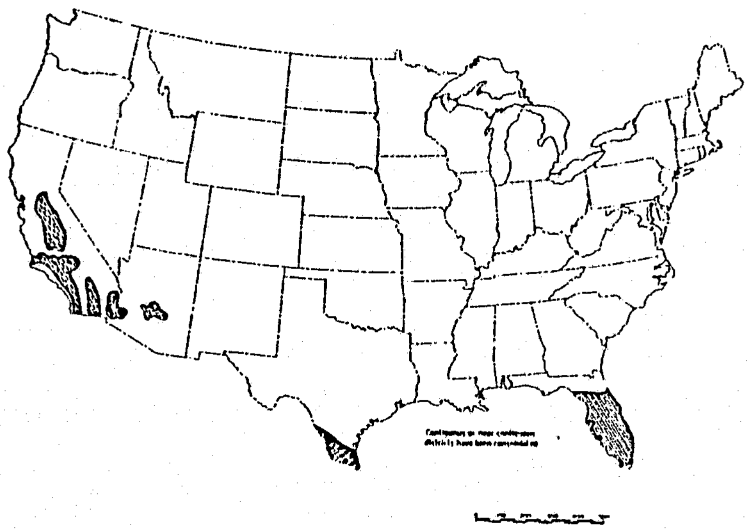


Figure 4.1 Citrus Producing Regions in the U.S.

The total U.S. citrus producing acreage is listed by state for the 1946 to 1974 time period in Table 4.1. There is a total of 1,116,700 citrus producing acres (excluding murcotts, limes and lemons) of which 791,000 acres (71 percent) are in Florida. The detailed geographical distribution of the two main citrus products, oranges and grapefruits, throughout Florida is shown in Figures 4.2 and 4.3, respectively.

4.2.1.2 Citrus Production by Variety and Dollar Value

The United States is the leading producer of citrus in the world. The total world production of oranges in the 1973-74 season was 767.5 million boxes, of which 240.3 million (31 percent) were produced in the United States. As far as the grapefruit production is concerned, the United States share is even larger. From the total worldwide crop of 82.8 million boxes, almost 71 percent (58.4 million boxes) were grown in the United States.

As already stated, Florida is the major citrus producing region in the United States. Florida produced 70 percent of the U.S. oranges and 82 percent of the U.S. grapefruits in the 1973-74 season as reported by USDA, Bureau of Agricultural Economics. Citrus is picked from October to July with about half of the total crop being harvested by the end of April. The total Florida citrus production by varieties from 1950 to 1975 is shown in Table 4.2.

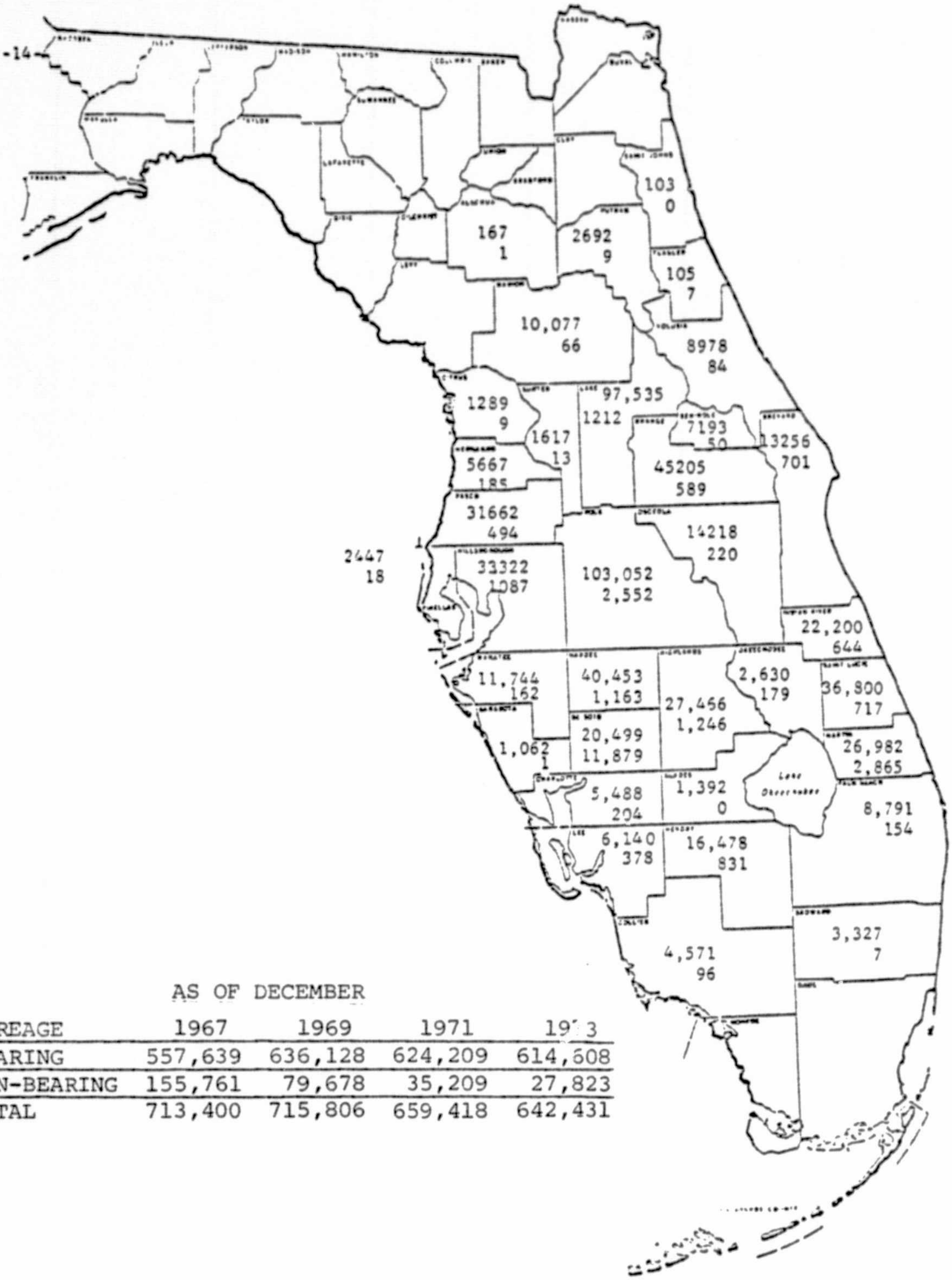
Citrus products reach the consumers in various forms: fresh, canned, frozen, concentrate, chilled juice, etc. While oranges are now predominantly processed (91.4 percent, Table 4.3), almost one-half of the grapefruits (42.1 percent) are consumed as

	ORANGES							GRAPEFRUIT				TANG-ERINE	TANGELO
	FLORIDA			CALIFORNIA									
Season	Early & Mids.	Vals.	Temples	1/Vals.	All	Tex.	Ariz.	Fla.	Calif.	Ariz.	Tex.	Fla.	Fla.
1946-47	156.1			149.2	234.0	32.9	7.1	85.7	14.1	12.9	80.0	23.7	
1947-48	162.1			148.9	228.6	35.5	7.8	87.6	13.3	12.2	80.5	23.8	
1948-49	167.5			149.2	222.7	40.5	8.3	89.5	11.6	10.3	82.0	24.0	
1949-50	174.3			134.8	215.1	28.0	8.3	93.0	10.7	10.0	56.0	24.0	
1950-51	179.0	130.5		132.5	211.6	28.0	8.5	94.4	10.2	9.0	56.0	22.5	
1951-52	185.8	139.0		130.0	207.7	17.7	8.3	98.6	9.7	8.9	17.9	22.8	
1952-53	190.6	146.8		126.5	200.8	17.2	7.5	102.2	9.4	8.5	20.9	23.0	
1953-54	179.7	153.8	14.8	120.0	192.2	16.7	7.1	105.5	9.1	7.0	22.0	23.3	
1954-55	185.8	166.4	16.5	112.9	183.2	24.1	6.9	111.2	8.2	6.0	24.1	23.9	
1955-56	191.5	172.5	18.3	102.5	180.0	26.0	6.8	111.8	8.3	6.0	26.0	22.0	2.1
1956-57	195.8	178.6	19.2	89.6	151.9	27.0	6.8	112.4	7.2	5.5	29.7	21.0	2.4
1957-58	168.3	184.1	20.1	86.6	148.6	28.7	6.8	95.0	7.5	5.4	30.1	16.2	2.7
1958-59	168.7	184.7	20.5	84.3	145.0	30.0	6.6	94.0	7.4	5.6	34.1	16.4	2.8
1959-60	171.7	198.3	21.6	78.7	138.7	31.9	7.4	92.3	7.6	5.6	38.1	17.8	3.2
1960-61	173.6	200.5	23.7	76.3	136.4	35.0	7.7	92.5	8.1	5.7	40.0	15.8	4.0
1961-62	182.8	225.9	21.1	72.1	131.6	35.0	8.7	94.0	9.5	5.8	45.3	15.4	5.6
1962-63	173.0	195.7	17.4	68.1	127.9	35.0	9.8	87.9	10.9	6.0	35.0	13.9	5.1
1963-64	183.0	192.0	16.0	66.8	127.7	26.0	11.7	83.0	11.9	6.0	36.0	12.1	4.5
1964-65	211.0	215.4	16.0	62.2	125.8	36.0	13.8	84.0	11.9	6.1	36.0	12.5	6.2
1965-66	232.0	248.9	17.0	63.2	128.7	27.0	14.1	86.0	12.0	6.2	37.0	12.8	7.0
1966-67	261.0	261.0	18.0	64.9	130.4	29.0	16.4	87.0	12.8	6.6	39.0	13.4	8.6
1967-68	283.4	273.6	18.3	70.7	139.9	31.0	17.0	87.5	12.8	6.7	41.0	14.8	10.6
1968-69	309.2	291.0	19.9	76.8	150.5	35.0	16.4	91.2	12.8	5.1	45.0	16.2	13.4
1969-70	332.1	303.7	21.8	84.4	160.2	35.0	15.5	98.7	12.8	6.1	40.0	18.6	18.1
1970-71	351.0	314.6	23.2	103.3	167.9	40.5	18.1	108.3	12.1	6.3	37.6	20.2	21.6
1971-72	322.4	300.6	22.4	83.2	188.8	42.5	19.5	112.6	13.1	6.4	35.0	19.2	18.4
1972-73	320.3	299.3	22.3	78.9	195.1	42.5	24.2	114.6	14.2	7.6	35.0	19.4	19.2
1973-74	316.2	298.3	21.9	78.6	199.4	N/A	24.4	115.7	15.9	8.2	N/A	19.1	19.8

Table 4.1 United States Bearing Acreage (thousands of acres)

1/Note: 1969-70 thru 1973-74 acreage from Valencia Orange Administrative Committee
Note: in 1963, there were 9,200 bearing acres of Honey Tangerines

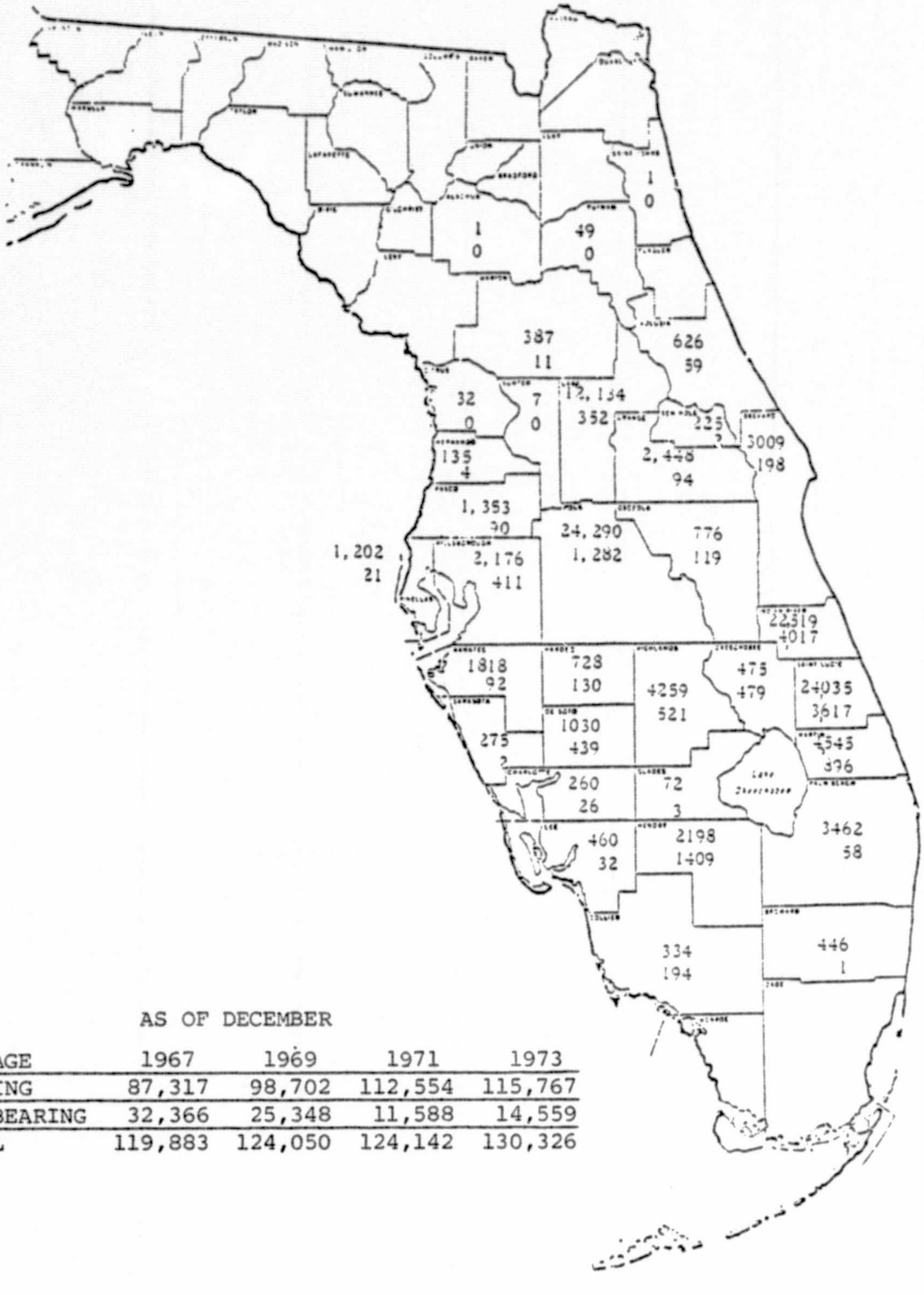
Source: Florida Crop & Livestock Reporting Service, Orlando, Florida.



AS OF DECEMBER

ACREAGE	1967	1969	1971	1973
BEARING	557,639	636,128	624,209	614,608
NON-BEARING	155,761	79,678	35,209	27,823
TOTAL	713,400	715,806	659,418	642,431

Figure 4.2 Florida's Total Orange Acreage Bearing and Non-Bearing as of December 1973 (Source: Florida Crop and Livestock Reporting Service, Orlando, Florida)



AS OF DECEMBER

ACREAGE	1967	1969	1971	1973
BEARING	87,317	98,702	112,554	115,767
NON-BEARING	32,366	25,348	11,588	14,559
TOTAL	119,883	124,050	124,142	130,326

Figure 4.3 Florida's Total Grapefruit Acreage Bearing and Non-Bearing as of December 1973 (Source: Florida Crop and Livestock Reporting Service, Orlando, Florida)

Table 4.2. Florida Production of Oranges, Grapefruit, Temples, Tangerines, Tangelos and Murcotts (thousands of boxes)

Crop Season	Oranges: Early & Midseason	Oranges: Valencia	Oranges: All Oranges	Grapefruit: Seeded	Grapefruit: White Seedless	Grapefruit: Pink Seedless	Grapefruit: All Grft.	Temples	Tangerines	Tangelos	Honey Tangerines	Total All Citrus
1950-51	35,700	30,500	66,200	17,400	15,800		32,200	1,100	4,800			105,300
1951-52	42,100	34,800	76,900	18,300	17,700		36,000	1,700	4,500			119,100
1952-53	40,600	29,900	70,500	15,400	17,100		32,500	1,700	4,900			109,600
1953-54	48,000	41,100	89,100	20,100	21,900		42,000	2,200	5,000			138,300
1954-55	49,500	36,400	85,900	14,300	20,500		34,800	2,500	5,100			128,300
1955-56	48,700	39,500	88,200	17,700	20,600		38,300	2,800	4,700	235	8	134,243
1956-57	51,600	38,700	90,300	15,800	21,600		37,400	2,700	4,800	320	30	135,550
1957-58	51,200	29,800	81,000	13,500	17,600		31,100	1,500	2,100	350	20	116,070
1958-59	43,900	38,900	82,800	15,600	19,600		35,200	3,200	4,500	300	90	126,090
1959-60	45,100	42,500	87,600	10,400	13,400	6,700	30,500	3,900	2,800	550	130	125,480
1960-61	47,000	35,700	82,700	12,400	11,900	7,300	31,600	4,000	4,900	500	230	123,930
1961-62	52,300	56,500	108,800	11,200	14,800	9,000	35,000	4,600	4,000	1,000	270	153,670
1962-63	43,500	29,000	72,500	10,000	12,500	7,500	30,000	2,000	2,000	750	100	107,350
1963-64	24,400	30,500	54,900	6,600	12,100	7,600	26,000	3,400	3,600	900	270	89,370
1964-65	42,600	39,800	82,400	10,200	13,000	8,700	31,900	3,800	3,900	1,000	230	123,330
1965-66	47,000	48,900	95,900	11,200	14,400	9,300	34,900	4,500	3,600	1,200	475	140,575
1966-67	73,200	66,300	139,500	13,500	18,600	11,500	43,600	5,000	5,600	1,800	670	196,170
1967-68	51,400	49,100	100,500	9,200	14,300	9,400	32,900	4,500	2,800	1,700	550	142,950
1968-69	69,700	60,000	129,700	12,200	17,000	10,700	39,900	4,500	3,400	1,800	1,100	180,400
1969-70	72,900	64,800	137,700	9,500	17,700	10,200	37,400	5,200	3,000	2,500	1,000	186,800
1970-71	82,100	60,200	142,300	11,800	20,200	10,900	42,900	5,000	3,700	2,700	970	197,570
1971-72	68,800	68,200	137,000	10,900	23,800	12,300	47,000	5,300	3,200	3,900	1,600	198,000
1972-73	90,000	79,700	169,700	10,200	23,500	11,700	45,400	5,100	3,000	3,500	900	227,600
1973-74	92,100	73,700	165,800	10,000	25,900	12,200	48,100	5,300	2,800	4,100	1,500	227,600
1974-75	96,600	76,700	173,300	7,200	25,900	11,500	44,600	5,300	3,100	4,700	1,650	232,950

Note: Oranges 90 lbs., Grapefruit 85 lbs, 90 lbs. Temples, Tangelos, Honey Tangerines, 95 lbs. Tangerines.

Source: Florida Crop & Livestock Reporting Service, Orlando, Florida

Table 4.3 Utilization by Outlets of Florida Oranges and Grapefruit

UTILIZATION BY OUTLETS OF FLORIDA ORANGES
Seasons 1974-75 thru 1971-72
(in 1,000 1-3/5 bu. boxes & 1,000 gallons)

ORANGES & TEMPLES

OUTLETS	1974-75	1973-74	1972-73	1971-72
Fresh, Interstate & Intrastate	11,908	10,071	12,135	9,734
Exports	1,017	436	197	145
Other use, non-commercial	2,376	2,508	2,436	3,257
TOTAL FRESH	15,301	13,015	14,768	13,136
Percent	8.6%	7.6%	8.4%	9.2%
Cannery Juice	6,516	6,594	8,001	6,485
Cannery Blend	486	625	693	633
Cannery Sections & Salad	100	65	72	98
TOTAL CANNERY	7,102	7,284	8,766	7,216
Percent	4.0%	4.2%	5.0%	5.1%
Frozen Concentrate (boxes)	135,512	132,469	132,210	104,399
*Frozen Concentrate (gallons)	178,174	171,846	176,073	134,229
Frozen Concentrate (yield)	1.31 gal.	1.30 gal.	1.33 gal.	1.29 gal.
Frozen Blend	3	6	1	11
TOTAL CONCENTRATE - boxes	135,515	132,475	132,211	104,410
Percent	75.9%	77.4%	74.6%	73.4%
Chilled Juice	22,783	20,448	20,479	19,503
Chilled Sections & Salad	528	608	656	535
TOTAL CHILLED	23,311	21,056	21,135	20,038
Percent	13.0%	12.3%	12.0%	14.1%
A. Total Processed	(165,928)	(160,815)	(162,112)	(131,664)
B. Total Processed	(163,299)	(158,020)	(160,032)	(129,164)
TOTAL UTILIZATION	178,600	171,100	174,800	142,300

* Net gallons, imports not included.
A. As reported by Florida Canners Association.
B. As reported by Citrus & Vegetable Inspection Division & Growers Administrative Committee. Use line B to balance total utilization.

Source: Florida Citrus Mutual

UTILIZATION BY OUTLETS OF FLORIDA GRAPEFRUIT
Seasons 1974-75 thru 1971-72
(in 1,000 1-3/5 bu. boxes)

OUTLETS	1974-75	1973-74	1972-73	1971-72
Fresh, Intrastate & Interstate	14,186	13,620	13,520	14,440
Exports	3,407	3,996	2,330	1,373
Other use, non-commercial	1,204	1,115	1,207	1,232
TOTAL FRESH	18,797	18,731	17,057	17,045
Percent	42.1%	38.9%	37.5%	36.3%
Cannery Juice	11,131	13,858	13,330	14,529
Cannery Sections	1,916	2,332	2,086	1,931
Cannery Blend	507	536	554	539
Cannery Salad	110	68	68	122
TOTAL CANNERY	13,664	16,794	16,034	17,121
Percent	30.6%	34.9%	35.3%	36.4%
Frozen Concentrate	7,762	8,728	8,211	8,718
Frozen Blend	17	4	1	7
TOTAL CONCENTRATE	7,779	8,732	8,212	8,725
Percent	17.4%	18.2%	18.1%	18.6%
Chilled Juice	3,338	2,722	2,906	3,206
Chilled Sections	546	467	510	445
Chilled Salad	421	654	703	550
TOTAL CHILLED	4,305	3,843	4,119	4,201
Percent	9.7%	8.0%	9.1%	8.9%
A. Total Processed	(25,748)	(29,369)	(28,365)	(30,047)
B. Total Processed	(25,803)	(29,365)	(28,343)	(29,955)
TOTAL UTILIZATION	44,600	48,100	45,000	47,000

A. As reported by Florida Canners Association.
B. As reported by Citrus & Vegetable Division, Growers Administrative Committee. Use line B to balance total utilization.

fresh fruits. The estimated F.O.B. (free on board) values of fresh fruit, frozen orange concentrate and chilled orange juice are listed in Table 4.4 and indicate the magnitude of the Florida citrus industry.

4.2.2 Historical Loss Data*

The Florida citrus production is influenced by many factors, such as fruit variety, age of trees, density of planting, topographical location, type of soil, weather conditions and nutritional and cultural practices. Many of these factors are under the control of the growers. Weather, being a collection of various atmospheric conditions such as rainfall, humidity, light intensity, amount of sunshine, temperatures, atmospheric pressure, etc., cannot be controlled.

From all bioclimatic factors influencing the citrus production, the freezing temperatures result in the heaviest losses in the citrus producing regions.

To illustrate the economic impact of a severe freeze on Florida's citrus industry, the damages to the crop as well as to the citrus bearing trees caused by the freeze in the 1962-63 season are considered. The most severe freeze of the century [1] caused temperatures to drop to 8°-11°F in Suwannee and Alachua counties and to 25°F as far south as Callier and Palm Beach counties on the mornings of December 13 and 14, 1962. The economic losses were staggering. The total loss was 50 million boxes of citrus [1] (32 percent of

*Does not include the unnecessary costs of frost protection (i.e., costs incurred for frost protection when frost was forecast but did not occur).

Table 4.4 Estimated F.O.B. Fresh Fruit Value of Florida Citrus, Frozen Orange Concentrate & Chilled Orange Juice - Interior and Indian River (in thousands of current dollars)

Season	All Oranges	Temples	All Grapefruit	Tangs.	Tangelos	Honey Tangs.	Total	Frozen Orange Juice	Chilled Juice
1958-59	$70,000	$10,800	$ 55,400	$16,100			$152,300	$239,200	
1959-60	68,500	13,200	54,400	14,700			150,800	232,500	
1960-61	73,200	14,200	49,500	17,100			154,000	251,600	
1961-62	73,100	13,300	53,200	16,900			156,500	236,600	
1962-63	56,500	6,900	58,200	10,800	$ 4,400		136,800	285,000	
1963-64	75,700	11,300	68,400	19,100	5,600		180,100	256,400	
1964-65	67,400	12,600	66,500	18,000	6,100		170,600	224,400	
1965-66	57,800	12,800	64,200	17,900	6,500		161,000	249,300	$ 60,400
1966-67	54,900	12,200	58,900	16,000	6,600		148,600	249,100	69,100
1967-68	83,400	17,700	74,400	19,400	9,150	$3,100	207,150	292,800	93,166
1968-69	60,000	12,700	54,200	15,800	10,700	2,900	156,300	328,400	95,000
1969-70	52,100	14,000	61,000	16,300	12,000	3,250	158,700	306,000	97,000
1970-71	43,648	10,800	63,600	15,367	6,600	2,405	142,352	380,000	128,000
1971-72	44,210	8,300	87,800	16,840	8,731	4,971	170,828	468,800	127,400
1972-73	50,129	13,171	90,427	14,935	8,007	4,666	181,325	492,000	128,300
1973-74	46,600	9,500	95,500	16,200	9,700	6,100	183,600	559,859	151,769
1974-75*	61,900	9,138	108,300	17,600	12,970	8,770	218,678	685,659	186,300

*Preliminary.

Source: Compiled by Florida Citrus Mutual, Statistical Division

1961-62 production of 152 million boxes), with an additional 50 million boxes of fruit having to be salvaged as concentrate. Furthermore, the freeze reduced the yield of concentrated juice obtained from the processed fruit. Prior to the freeze, a yield of 1.55 gallons of concentrate per box was estimated for that part of the total orange crop intended to be used for the frozen concentrate orange juice. The actual yield was 1.09 gallons of concentrate per box [2]. Besides the loss to the crop, the trees sustained damage as well. About 7 to 10 million trees were killed.

Not only was the 1962-63 citrus production very low (106 million boxes) but also the next season (1963-64) was severely affected due to the loss of trees, and the production was even lower (92 million boxes) than in the 1962-63 season. It wasn't until 1966-67 that recovery in Florida was sufficient for total citrus production to exceed the level of the 1961-62 season.

The losses to the crop were covered by the Federal Crop Insurance Corporation (FCIC) on 8 percent of the total citrus producing acreage [4] in 1975; in Florida it was estimated that only 14 percent of all growers used this insurance (1975). FCIC paid to Florida citrus growers $5.1 million in indemnities for 1962-63 losses (even fewer than 14 percent of growers were insured in that year by FCIC) and a total of $19.2 million for losses between 1962 and 1970 due to "frost, freeze, cold and winter kill." This represents 97.5 percent of the total indemnity paid in that period.

Table 4.5 summarizes the freezes which have occurred since 1939, indicating the estimate of the citrus crop (oranges

Table 4.5 Historical Freezes Which Influenced Citrus Crops, 1939-40 Through 1973-74 Seasons.

Seasons	Description of Freeze	Monthly Production Estimate[a] (10^6 boxes)	Final Production (10^6 boxes)
1939-40	During the dates of January 27, 28 and 29 temperatures of 15°and lower covered the upper one-third of the state. Temperatures in the low 20's covered the remainder of the state.	na[b] na	26[c] 16[d]
1946-47	On February 6 temperatures were in the low 20's in the North and in several pockets throughout the State. Temperatures in the mid 20's covered the remainder of the state except along the southern coast.	na na	54 29
1957-58	Freezing temperatures occurred on December 12 and 13 in the northern and central areas of the state. On February 4 and 5 temperatures in the mid 20's covered the entire state.	102 36	82 31
1962-63	A "big" freeze in all areas of the state during the period December 11-15 produced the "greatest citrus loss in history." Below normal temperatures occurred during each month of the winter season.	120 38	74 30
1969-70	Temperatures of 28° and lower occurred January 7-11 which damaged fruit in the northern and central districts. Temperatures of short duration in the mid 20's occurred in the northern and central districts on February 4 and caused minor damage. Loss of fruit due to the freeze was minimum, but juice yield was reduced.	140 37	143 37
1970-71	Freezing temperatures and heavy frost occurred on November 25 in all agricultural areas except the lower east coast. Heavy fruit and wood loss occurred in Hillsborough County on January 20 and 21 as severe freeze in the upper teens covered all areas except the lower east coast.	175 49	147 43

[a]Refers to the monthly estimate of the Florida Crop and Livestock Reporting Service which preceeded the first freeze of the season, providing the freeze occurred prior to the 10th of the month. For example, if a freeze occurred prior to January 10, the December estimate is listed. If the freeze occurred after January 10, the January estimate is listed.

[b]Not available.

[c]Oranges

[d]Grapefruit

Source: Florida Canners Association, Florida Citrus Mutual and Florida Crop and Livestock Reporting Service.

and grapefruits only) and the final production in each season. The original USDA estimates of citrus production (by variety) are compared with the actual production in Table 4.6. The influence of freezing temperatures during the winter season on citrus crop production is readily apparent.

The value of production of oranges lost due to frosts and/or freezes is illustrated as follows: It was estimated by the USDA (Table 4.6) that the total production of oranges would be 174.5 million boxes during the 1970-71 season. The actual production was only 147.3 million boxes. The loss of 27.2 million boxes of oranges can be attributed primarily to the rather severe freezes in that season. The average price for delivered-in oranges for concentrate was $2.07/box [13], and the FOB average for freshly packed oranges was 2.13/box [13]. Since only about 10 percent of orange production was used as fresh fruit (Table 4.3), the total value of the orange production lost in that year was approximately $56.4 million. Even if the increase in prices for both delivered-in oranges and fresh packed oranges after the freeze is considered, the magnitude of losses indicates the importance of the frost protection for the citrus industry.

There are additional losses in the citrus production due to ice, rain, hail and hurricanes, but all these are minor compared to losses caused by freezing temperatures.

Table 4.6 Original Government Estimates For Seasons 1968-69 Through 1974-75 As Compared With Season Total Production (in thousand of boxes) 1/

	ORANGES				GRAPEFRUIT			
	*Early & Midseason		Valencias		Seeded		Seedless	
Season	Orginal Estimate	Actual Production	Original Estimate	Actual Production	Original Estimate	Actual Production	Original Estimate	Actual Production
1968-69	73,000	74,200	56,000	60,000	13,000	12,200	29,000	27,700
Over & Under	-1,200		-4,000		+ 800		+1,300	
	Comment:	Some freeze damage in northern and central area. Rainfall plentiful during season except April & May. No hurricane damage						
1969-70	87,000	78,100	62,000	64,800	10,000	9,500	27,900	27,000
Over & Under	+8,900		-2,800		+ 500		+ 900	
	Comment:	Severe cold January 7,8,9,10,11. Some damage in northern and central districts. Rainfall for season adequate to some excess during winter, dry during April and March.						
1970-71	100,500	87,100	74,000	60,200	15,000	11,800	34,000	31,100
Over & Under	+13,400		+13,800		+3,200		+2,900	
	Comment:	Severe cold Nov. 25, Jan. 20-21, Feb. 8. Freeze damage severe in many areas. Near drought conditions over central & southern areas during most of the year.						
1971-72	73,000	74,100	64,000	68,200	10,000	10,900	33,000	36,100
Over & Under	-1,100		-4,200		- 900		-3,100	
	Comment:	Warmest winter on record. No freeze damage, no hurricanes. Rainfall was spotty.						
1972-73	92,000	90,000	82,000	79,700	11,000	10,200	34,000	35,200
Over & Under	+2,000		+2,300		+ 800		-1,200	
	Comment:	No freeze, no hurricanes. Rainfall ample from June to date.						
1973-74	93,000	92,100	72,000	73,700	10,500	10,000	37,500	38,100
Over & Under	+1,100		-1,700		+ 500		- 600	
	Comment:	No major cold weather, severe dry weather, January through May. No hurricanes through August. More than ample rainfall June, July and August.						
1974-75	102,500	101,900	77,000	76,700	9,500	7,200	35,500	37,400
Over & Under	+ 600		+ 300		+2,300		+1,900	
	Comment:	Generally mild winter, severe drought first five weeks, no hurricanes. Ample rainfall during June, July and August.						

*Temples included.

Source: Florida Citrus Mutual, Annual Statistical Report, 1974-75 Season
1/ 90 lb. oranges, 85 lb. grapefruit.

4.2.3 Weather Sensitivity of Citrus

4.2.3.1 Meteorological Characteristics and Frequencies of Frosts and Freezes

There are basically two types of frosts, namely, the advective (referred to as freeze) and the radiational (referred to as frost).

An advective freeze occurs when a mass of cold, dry air having thickness of 500 to 5,000 feet is transported from the polar regions by winds having velocity exceeding 5mph. A cold front of dense air displaces a warmer air mass very rapidly as it moves southward. The temperature falls rather uniformly throughout the night (Figure 4.4) during the advective freeze on low grounds as well as high grounds. Pockets of warmer air remain in valleys (Figure 4.5).

A radiational frost occurs when air, soil and plants are cooled to freezing temperatures through loss of heat by radiation. The thickness of the cold air mass is between 30 to 200 feet and moves slowly with wind velocity under 3mph. The surfaces of plants and earth exhibit a heat loss at a greater rate than the surrounding layer of air which is cooled by this radiation and, through the thermal conduction, cools the subsequent layers of the atmosphere. This process results in a temperature inversion, when air temperature increases with the increasing height above the ground. Also, as a consequence of the thermal inversion during the radiational frosts, there are higher temperatures on high grounds and lower temperatures on lower grounds (Figure 4.6 and 4.7). The cooled air is heavier than the dry air and flows down due to the gravitational forces into lower elevations. If there are depressions in the sloping terrains, very cold frostpockets are formed.

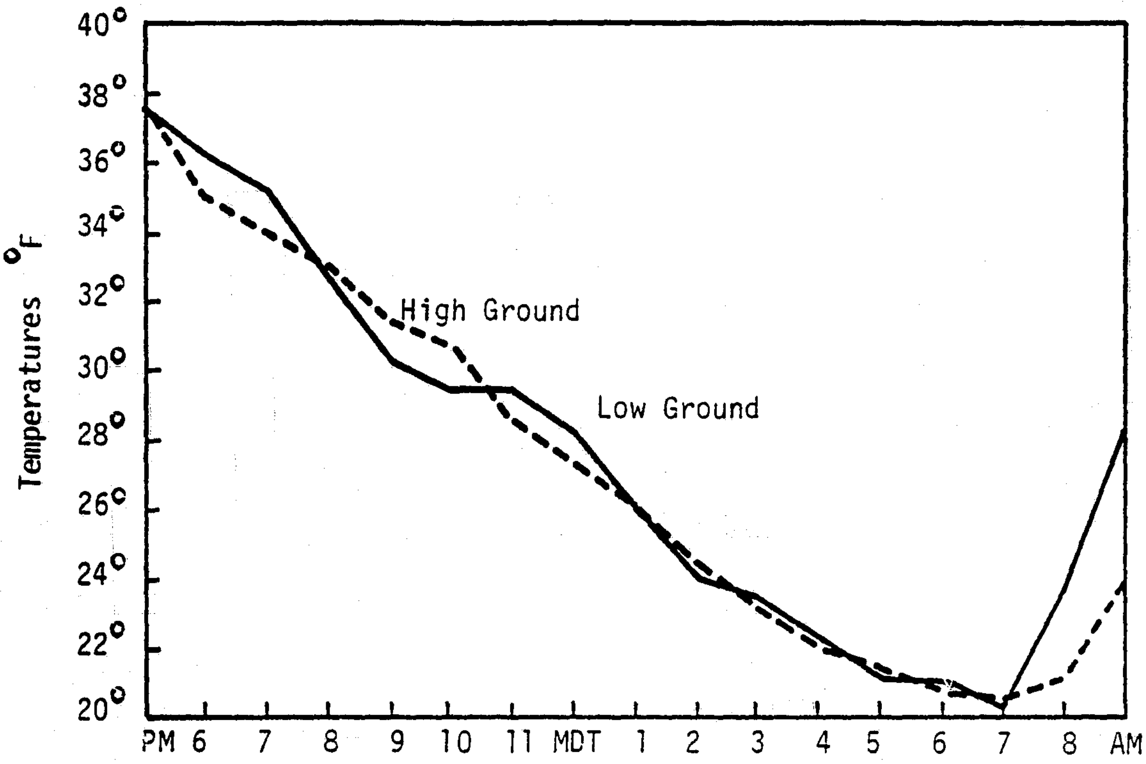


Figure 4.4 Typical Temperature Progression for Advective Freeze Indicating Little Difference in Temperatures on High and Low Ground Locations on a Windy Night. (Source: Ref. 1)

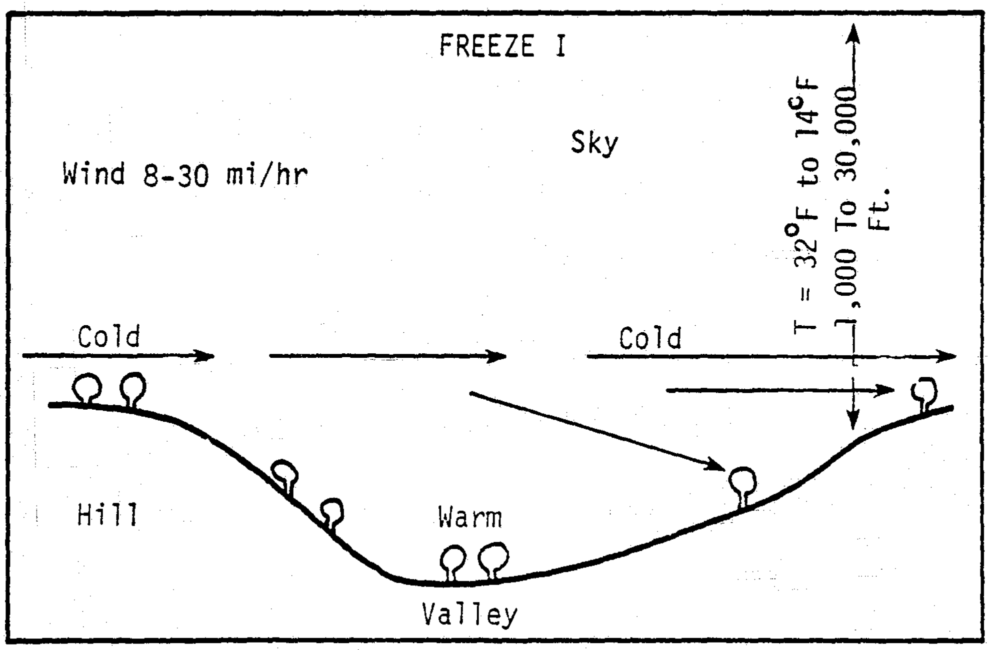


Figure 4.5. Diagram Showing Micrometeorology of a Freeze in Hilly Country. In flat country, micro-meteorology is similar to hilltop on left. (Source: Ref. 3)

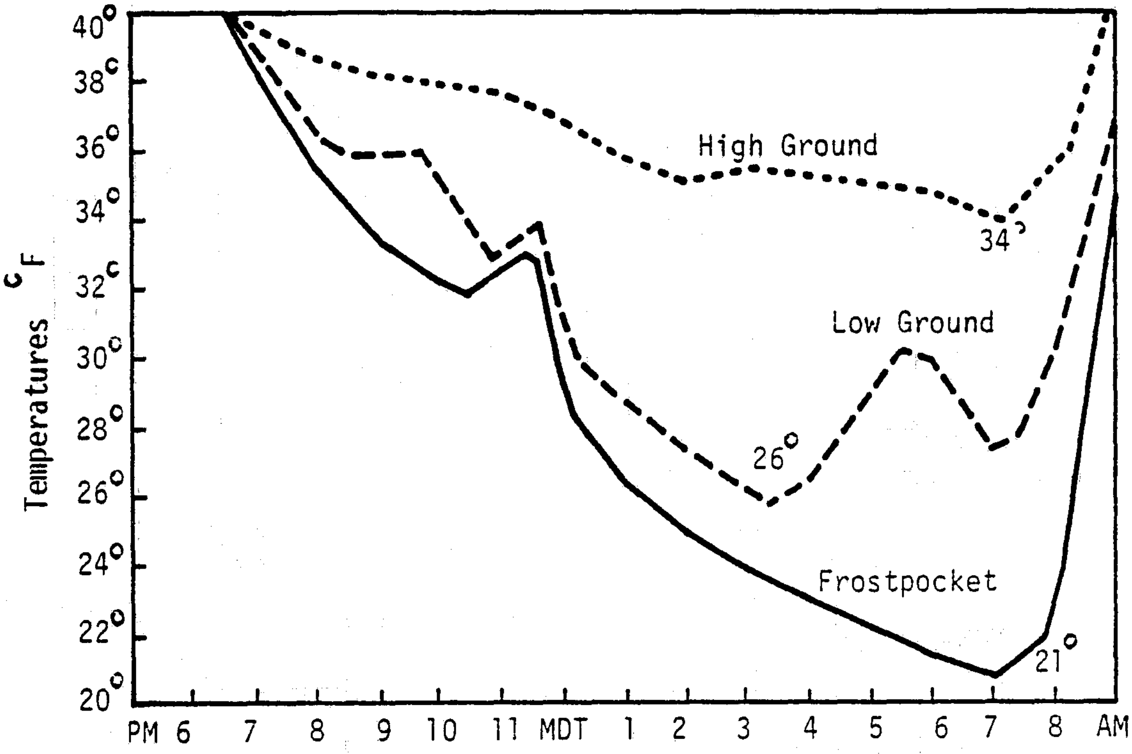


Figure 4.6 Typical Temperature Progression for Radiational Freeze Indicating Considerable Difference in Temperatures with Elevation. Night - clear skies with long periods of calm. (Source: Ref. 1)

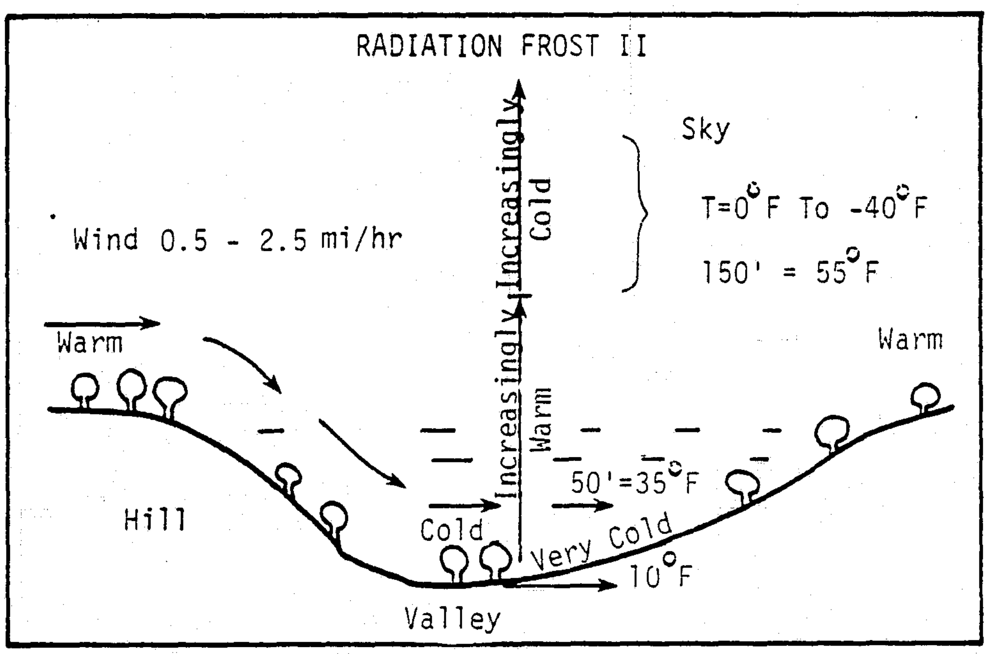


Figure 4.7. Diagram Showing the Micrometeorology of a Radiation Frost in Hilly Country. A radiation frost may develop alone or as the second stage (calm) of an advection freeze. In the latter case, the hilltop trees enter the second stage very cold while the valley trees enter the calm night somewhat warmer. (Source: Ref. 3)

An elevation difference of as little as 4 to 5 feet above a surrounding area can cause an increase of from 2° to 5°F on cold, clear and calm nights. If there is an air flow of the warmer air in a layer 10 to 40 feet above the tree tops, the rising colder air (due to the inversion) mixes with the warm air of upper layers and the resulting turbulance is often sufficient to prevent the development of radiation frosts.

A relatively high atmospheric moisture results in formation of small crystals on plants and soil, so called hoar or white frost, when soil and plants are cooled to the dew point temperature.* A low atmospheric moisture, when dew point is lower than the soil and plants surface temperatures, results in black frost since the air is too dry to form crystals. Radiational frosts are characterized by calm winds, clear skies and low atmospheric water vapor content.

The very damaging freeze-frost combinations occur when cold, freezing winds are replaced by calm periods of radiational frost. A typical Florida freeze may last two days. The first night is usually a cold windy advective freeze but rarely a seriously damaging one. Usually there is a little warming of the air or trees during the second day as cold air continues to move south. During the second night the wind usually falls soon after sunset and the stratifying air may reach dangerously low temperatures rather soon, especially in low areas. This is when the greatest damage to fruit and trees is done. On the third day the wind usually shifts and begins to

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*The dew point temperature is that temperature where the moisture in the air begins to condense onto leaf surfaces.

replace the cold air with warmer air from the ocean. The most severe damage results when an early winter freeze is followed by a period of warm weather sufficient to initiate new growth which in turn is followed by a second freeze in the same winter. The trees are much more susceptible to freezing temperatures because of the new growth and are then killed to the ground.

The movement of a mass of cold polar air into subtropical regions associated with an advective freeze results in very low air temperatures between 8°F and 28°F. The probability of occurrence of these temperatures is small in December, increases throughout January and decreases from the middle of February. The records show that several severe freeze-frost combinations occurred in late November and milder radiational frosts even in April.

The temperature records in Florida go back to 1747 but it is not possible to distinguish if the freezing temperatures were advective freezes or radiational frosts. The study of the frequency of cold-weather events [5] shows that, for example, in the Ocala-Weirsdale region of Florida there was a 2.5 year interval between frosts or freezes in the 22°-25°F range and a 3.1 year interval between frosts or freezes under 22°F during the observation period 1894-1958. The geographical influence can be easily observed since in the nearby Orlando area the interval between frosts or freezes under 22°F was 8 years during the same observation period.

Growers can use the past record to help them to establish a weather probability used in planning frost-protection measures.

4.2.3.2 Frost Protection Technology and Factors Influencing Its Use

The research [3] in the areas of enviromental physiology indicates that there is a dynamic energy exchange between the plant's tissues and its enviroment which, together with other factors such as air temperature, wind velocity, relative humidity, soil moisture and fertility, regulates the process of growth and development as well as the conditions during frosts and freezes. The decision to use or not to use a particular frost protection method is influenced by these factors and some additional natural features in and around an orchard. There are local topography and possibility of thermal inversion, windflow paths, type and chemical state of soil, temperature of the water used for irrigation or sprinkling, temperature of the ground, availability of cover crops and windbreaks, proximity of large bodies of water and other citrus orchards and dormancy status of trees (dormant trees are less susceptable to frost damage [9]).

The excessive heat loss of the plants results in the frost and freeze damage to plants. The complex heat transfer system consists of heat exchange between parts of a plant, plant and ground, plant and air, ground and air, and finally plant, ground, air and sky. The infrared radiation from ground and plants is absorbed by water vapor. This absorption increases with an increase of water vapor in air.

With relative humidity close to 100 percent and sufficient thickness of clouds (about 165 feet) all terrestrial radiation is absorbed and almost three-quarters of it is reradiated back to earth.

Radiation frost does not normally develop when the air is calm and there are clouds or fog even if the temperature is low enough to cause frosts when the sky is clear.

The heat stored in soil is released during the cold nights. The amount of heat radiated from moist sandy soil (sandy soils prevail in Florida) is greater than from muck soil [2] (found mostly in Everglades). Because sandy soils have greater heat capacity and thermal conductivity they do not cool the surrounding layer of air as much as does the muck soil.

The proximity of lakes and reservoirs to orchards is most beneficial during advective freeze nights. Much of the heat stored in these large bodies of water during the warm period, because of water's large heat capacity and thermal conductivity, is then picked up by the air in passing over the water surface and is recovered by leeward trees in the orchard.

The most common protective system of a citrus grove against freezing temperatures consists of a combination of the two principal methods of frost protection: using heaters to generate heat, and using wind machines for redistributing heat in and above the orchard. Heaters have proved to be the most efficient in the heating of citrus orchards. Oil heaters are very effective in combating long advective freezes. Most heaters currently in use have a capacity to burn all night (up to 6 hours) without refueling, are relatively easy to light under all weather conditions and satisfy the environmental standards (do not produce excessive smoke). Return stack, jumbo cone and lazy flames are the most commonly used heaters in Florida.

Heat released from heaters by burning fuel is in convective and radiational forms. Convective heat in the form of hot gases and heated air are distributed throughout the grove by movement of air. Radiational heat is released from the flame and heater stacks. Trees close to heaters are warmed by radiant heat rather than by convective heat.

The effect of heaters is greatly reduced by radiational losses of heat directly to the sky from the top of a grove and by light hot air, warmed by convectional heat, being blown away by the wind. The total losses from an unprotected citrus grove on cold calm nights range from 0.9 to 1.8 million BTU/acre/hour [10]. Because of the above stated losses, the total heating system should provide 3 to 5 million BTU/acre/hour to adequately protect an orchard.

There are several other factors which influence the effectiveness of cold protection by heaters, the most important of which is wind. Since the hot air is blown away by wind, protection is greatly reduced on windy nights. Windbreaks reduce the velocity of wind and increase heating efficiency. Border areas of an orchard require additional heaters for good protection because of an inflow of cold air. The effect of wind is reduced for larger groves since the trees tend to reduce the wind speed. Size of trees also plays an important role. Large trees resist the wind and their canopies are also large and intercept more radiant heat.

Refueling of heaters represents a problem during long duration advective freezes (a heater can hold up to 9 gallons of fuel). Normally, insufficient laborers are available to distribute the fuel. Some growers, therefore, use more heaters than necessary so they have enough fuel for two nights. A system with permanent oil supply pipes

eliminates this problem but requires a large capital expenditure and is therefore used primarily in nurseries.

As stated earlier, a wind machine redistributes the heat in the layers of air by producing enough turbulence to break up the temperature inversion of the air and mixing its warm and cold components. This mixture is then transported across the orchard and the cold air is pushed out until a pressure equilibrium is set up between the mixture in the orchard and cold dense air outside the orchard. One wind machine (30 brake horsepower-bhp) can protect 3.5 to 6 acres. Several wind machines operating together provide greater temperature response per machine than one. Large machines (90 bhp) also provide greater protection in low spots.

The efficiency of wind machines depends on the thrust and reach of propellers in relation to the power source. The thrust and reach decreases with decreasing temperatures as air density increases and viscosity decreases. The wind machine's reach on a very cold night is about 50 percent of the reach on a warm day [3]. Wind machines offer advantages in cold protection because they minimize labor requirements, require less refueling and less fuel storage than heaters, are permanently located in the grove, have a low operational cost per acre, and do not produce smoke and air pollution. These advantages must be weighed against the disadvantages of rather high capital costs and the failure of the wind machine to provide adequate cold protection under all conditions.

There are other methods of cold protection, such as utilizing the proximity of lakes and reservoirs, creating windbreaks, providing proper air drainage, and also irrigation, sprinkling, chemical spraying, insulation of trees, and manmade fog. These methods are not normally used in commercial citrus production. A comparasion of major grove-heating systems is presented in Table 4.7.

Overhead water sprinkling as a frost protection measure has several advantages. The sprinkler system can be started and stopped easily, the labor cost is minimized and the sprinklers are used for regular irrigation. The system must be capable of supplying enough water so there is a continuous supply of heat obtained from freezing of water drops.

Sprinkling was successful in Florida only in protection of nursery trees but was a complete failure in mature citrus groves. The ice which accumulated on citrus trees caused breakage of branches due to the excessive weight. The failure of this system could be attributed to dry air, very rapid drop in temperature due to the strong wind and resulting evaporative, convective and radiative cooling being greater than the heat released by sprinkling.

4.2.4 Current Forecasting Capability

4.2.4.1 Frost Warning System in Florida

The vulnerability of the citrus crop to the effects of freezing temperatures and the impact of an accurate and timely weather forecast have been recognized for a long time. The Federal-State Agricultural Weather Service was established in the citrus belt of Florida, with headquarters in Lakeland, in 1935 and later

Table 4.7 A Comparison of the Important Grove-Heating Systems

System	Radiant Heat	Effectiveness: With Low Ceiling	Effectiveness: With High Ceiling	Effectiveness: As Border Heater	Air Pollution	Efficiency (BTU/Degree Temp.Rise)	Costs: Fixed Capital	Costs: Fuel	Costs: Labor
Lard pail*	Poor	Good	Poor	Good	Poor	Poor	Good	Fair	Fair
Lazy Flame	Fair	Good	Poor	Fair	Fair	Poor	Fair	Good	Fair
Jumbo cone	Good	Excellent	Fair	Poor	Good	Fair	Poor	Good	Fair
Return stack (gas or oil)	Good	Excellent	Fair	Poor	Good	Fair	Poor	Good	Fair
Pipeline	Fair	Excellent	Poor	Good	Fair	Fair	Poor	Good	Good
Wax candles	Poor	Good	Poor	Good	Poor	Fair	Excellent	Poor	Poor
Wind machines	Poor	Excellent	Poor	Poor	Excellent	Excellent	Poor	Excellent	Excellent
Wind machines and heaters	Fair	Excellent	Good	Good	Good	Excellent	Poor	Excellent	Good
Petroleum coke bricks	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Poor	Fair
Heaters and petroleum coke bricks	Good	Excellent	Excellent	Excellent	Good	Good	Fair	Good	Fair
Wind machines and petroleum coke bricks	Fair	Excellent	Good	Excellent	Good	Excellent	Poor	Excellent	Good

*Not acceptable where smoke controls exist.
Source: Albrecht (1967), Reference 3.

extended to cover the whole peninsula. The forecast bulletins issued twice a day during the frost season (from November 1 through March 31) provide the growers with an estimate of the geographic distribution of the anticipated minimum temperatures. The forecast districts, together with a guide how to use the forecasts, are shown in Figure 4.8.

The weather forecasting function of the Federal-State Agricultural Service was incorporated into the National Weather Service with Florida headquarters in Ruskin, and the forecast districts were changed into the forecast zones shown in Figure 4.9. All forecasts are now made from Ruskin.

The minimum temperature forecast, accompanied with an outlook for the next one to three nights, and forecasts of clouds and winds are the main function of NWS Agricultural Weather Service. The other functions [11] are:

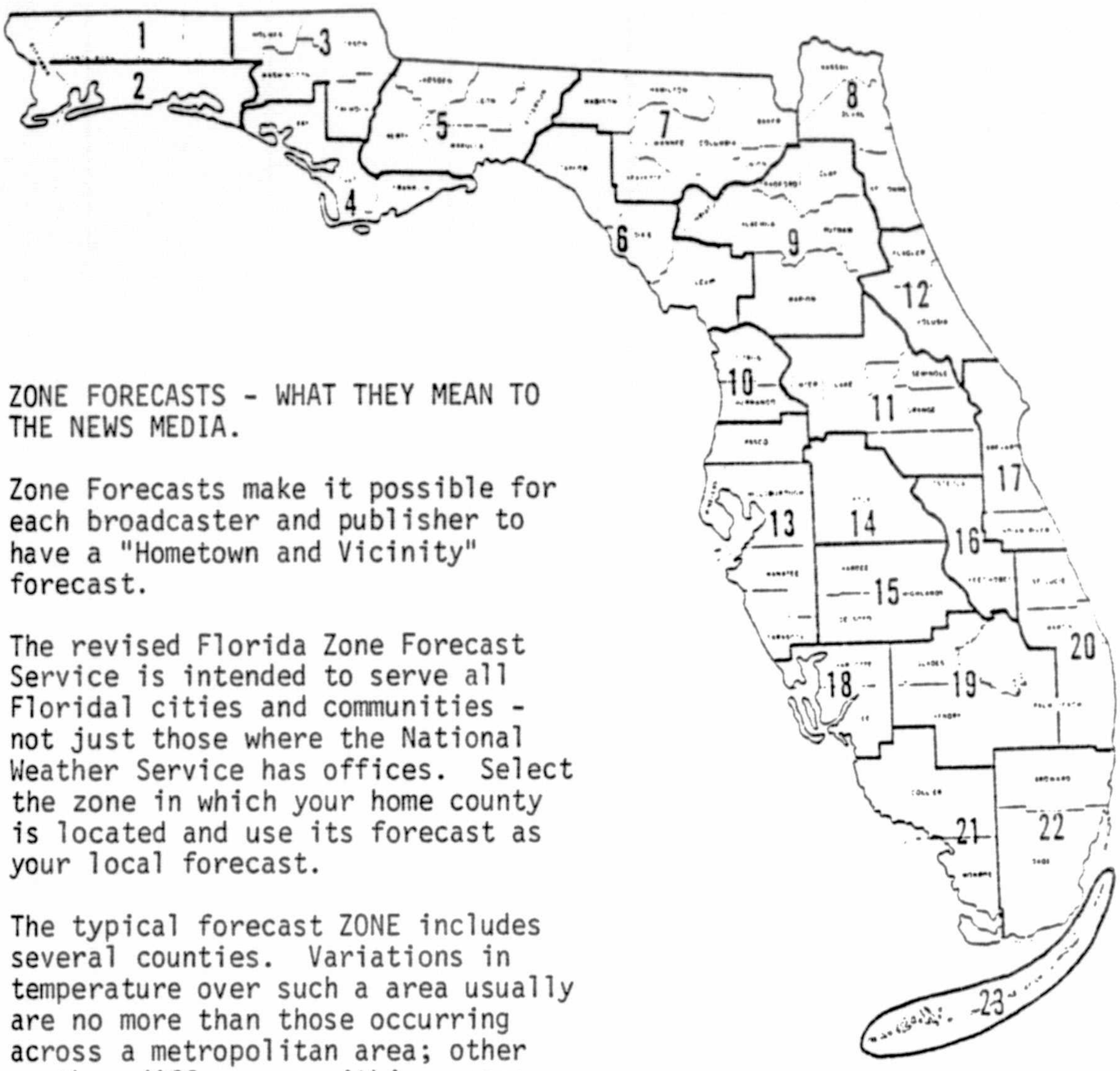
a. to offer an advisory service of how to prevent damage from frost and/or freezes,
b. to provide temperature durations for key stations throughout the growing areas (these are available immediately following nights of frost damage),
c. to compile annual reports on the general character of each season with respect to crop-weather relationship, tabulations of minimum temperatures from stations within the forecast area for selected nights, durations of temperatures below 32° from all survey stations and comparative data and observations,
d. to make temperature surveys in new or old agricultural

HOW TO USE THE FORECAST

For the benefit of growers who use our forecasts as a guide in frost protection operations, we find it necessary to locate our forecast stations in the colder, low ground locations. If we selected warmer, high ground locations we would be forced to issue "no danger" forecasts on many nights when damaging temperature would be experienced in the low-lands. There is usually considerable difference in temperature between high and low ground. It is impossible to name a single definite temperature that will fit all groves in a locality. Growers may adapt our forecasts to their own location by keeping records for a period of time and then comparing them with those from a nearby forecast station. Then it is easy to estimate how much warmer (or in rare instances colder) their own property may be than the cold, low ground locations for which the forecasts are issued. In the first part of the bulletin a statement is made as to how much difference may be expected between high and low ground locations in the various districts. The amount may be very small on windy nights or may be 10 degrees or more on calm, clear nights. Moderately high ground would, naturally, be somewhat less. After making comparisons for a period of time, it should be easy for the individual property owner to adapt the forecasts to his own property. For example, the temperature forecast for low ground in an area is 24° to 27° and high ground is to be 8 degrees warmer. It can readily be ascertained that the temperature expected for high ground grove will be 32° to 35°.

Figure 4.8 Map Showing Forecast Districts as Were Used in the Forecast Bulletin Issued Twice Daily from November 1 Through March 31 (Source: Federal-State Agricultural Weather Service, Lakeland, Florida)

FLORIDA FORECAST ZONES
(Revised October 1, 1972)



ZONE FORECASTS - WHAT THEY MEAN TO THE NEWS MEDIA.

Zone Forecasts make it possible for each broadcaster and publisher to have a "Hometown and Vicinity" forecast.

The revised Florida Zone Forecast Service is intended to serve all Floridal cities and communities - not just those where the National Weather Service has offices. Select the zone in which your home county is located and use its forecast as your local forecast.

The typical forecast ZONE includes several counties. Variations in temperature over such a area usually are no more than those occurring across a metropolitan area; other weather differences within a zone are usually little different. The Zones shown in the map on this page are revised as of October 1, 1972 to better meet the needs of the using public.

Figure 4.9 Map Showing Florida Forecast Zones as Used by the National Weather Service (Source: National Weather Service, Southern Region Headquarters, Fort Worth, Texas)

areas which provide invaluable information to prospective agricultural development,

e. to study temperature and crop relationships, researching the meteorological relationship with respect to methods and equipment for frost protection, etc.

4.2.4.2 Frequency and Dissemination of Frost Forecasts

Currently the official weather forecast by the National Weather Service (NWS), is made four times a day, at 6:00 a.m., 10:15 a.m., 4:15 p.m. and 10:15 p.m. The early morning forecast at 6:00 a.m. is a temperature outlook for the next twenty-four hours for the whole state. No detailed meteorological data are forecast.

The 10:15 a.m. forecast is the next important forecast of the day. The weather prediction is based on the data obtained from the meteorological soundings, the readings of government thermometers throughout the state (about 200 thermometers), and the additional data obtained from the weather stations, such as the heat flux from the earth, radiational losses, etc. The forecast begins with a preamble for the whole peninsular Florida which gives qualitative indications about temperature, the minimum temperature and its approximate time of occurrence, wind direction and wind speed, and finally information on any possible temperature inversion. The preamble is followed by detailed temperature forecasts expressed as a 4°F interval for each forecast zone.

The 4:15 p.m. forecast is an update of the 10:15 a.m. forecast based upon the additional temperature readings of the government thermometers. There is no input from the meteorological soundings

(they are launched only twice a day). This forecast rarely deviates from the 10:15 a.m. forecast. Typical 10:15 a.m. and 4:15 p.m. forecasts are presented in Figures 4.10 and 4.11 respectively.

Finally, the 10:15 p.m. forecast is an update of the 4:15 p.m. forecast and includes changes in weather problems that may occur. Normally, if the 4:15 p.m. forecasted temperatures are above 28°F, the 10:15 p.m. forecast is not given.

There are several means of forecast dissemination, such as teletype, public radio and telephone. Typically, a grower receives the official NWS forecast on his own teletype which costs him $100/month for the teletype line. The official NWS forecast is rebroadcast by public radio stations and also disseminated via radio by 24 hour continuous weather broadcasts, updated every six hours, with taped messages repeated every 4 to 6 minutes. Many growers have special receivers which enable them to listen to this VHF-FM radio broadcast at frequencies of 162.55 MHz and 162.40 MHz.

4.2.4.3 Informal Non-NWS Forecasts

Besides these public means of dissemination, the growers can obtain the latest forecast by calling the unlisted telephone number of the NWS Office at Ruskin or Federal-State Agricultural Weather Service at Lakeland and listening to the recorded official NWS forecast. This is beneficial especially to smaller growers who cannot afford to have the teletype service. The growers also communicate extensively among themselves and exchange information about temperatures obtained from their thermometers. There are no official (by NWS) temperature readings of government thermometers after dark,

MANN
ZCZC
FXUSS RWRB 281515

PENINSULAR FLORIDA FARM AREA MINIMUM TEMPERATURE FORECAST
ISSUED AT 10:15 AM EST WEDNESDAY JAN 23 1975
NATIONAL WEATHER SERVICE TAMPA BAY AREA RUSKIN FLORIDA

FOR TONIGHT FROST AND FREEZE WARNING ALL ZONES
CLEAR AND COLD ALL ZONES. TEMPERATURES WILL DROP STEADILY DURING THE NIGHT
WITH LOWEST TEMPERATURES NEAR SUNRISE. WINDS LIGHT AND VARIABLE
WITH PERIODS OF CALM AFTER MIDNIGHT.

LOWEST TEMPERATURES

ZONES 6 7 8 22 TO 26 FROST

ZONE 9 24 TO 28 FROST

ZONES 10 11 12 13 14 15 16-28 TO 32 POCKETS AND COLDER LOCATIONS
26 TO 23 WITH FROST.

ZONE 17 32 TO 36 SCATTERED FROST

ZONES 18 19 21 34 TO 40 PATCHY FROST PACKLANDS.

OUTLOOK FOR THURSDAY NIGHT...NOT AS COLD. CHANCE OF FROST
AGAIN CENTRAL AND NORTH PORTION.

Figure 4.10 Typical 10:15 a.m. Forecast

FAUSB RWRB 28211

PENINSULAR FLORIDA FARM AREA MINIMUM TEMPERATURE FORECAST
ISSUED AT 4:15 PM EST WEDNESDAY JANUARY 28 1976
NATIONAL WEATHER SERVICE TAMPA BAY AREA RUSKIN FLORIDA

FROST AND FREEZE WARNINGS

TONIGHT...CLEAR AND COLD ALL ZONES. TEMPERATURES FALLING STEADILY
DURING THE NIGHT WITH LOWEST TEMPERATURES TO OCCUR NEAR SUNRISE.
LIGHT AND VARIABLE WINDS WITH PERIODS OF CALM AFTER MIDNIGHT.

LOWEST TEMPERATURES

ZONES 6 7	20 TO 24 FROST
ZONES 8 9	24 TO 28 FROST
ZONES 10 11 12	26 TO 30 WITH 24 TO 26 COLD POCKETS AND MUCKLANDS. FROST
ZONES 13 14 15 16	28 TO 32 WITH 26 TO 28 COLD POCKETS AND MUCKLANDS. FROST
ZONE 17	32 TO 36 SCATTERED FROST
ZONES 18 19 21	33 TO 37 SCATTERED FROST
ZONES 20 22	35 TO 40 PATCHY FROST

TEMPERATURE OUTLOOK...NOT AS COLD. CHANCE OF SCATTERED FROST
NORTHERN ZONES FRIDAY MORNING.

Figure 4.11 Typical 4:15 p.m. Forecast

only the unofficial data provided by the growers. Importantly though, meteorologists of Federal-State Agricultural Weather Service give an informal "localized" forecast for growers' particular regions by phone which is based on the above unofficial data and information from NWS. Besides the temperature range, they also provide the probabilities with which these temperatures will occur. This type of constant communication usually lasts on a cold night until 1:00 a.m. By that time the growers have decided whether to initiate a frost protection action or have assumed that the temperature will not become low enough to cause any damage.

4.2.5 Frost Protection Decision Process

4.2.5.1 Factors Influencing Growers' Decision to Protect

The decision of a grower to initiate protective action against freezing temperatures, assuming that they are forecasted for a coming night, depends upon a number of factors which have to be considered simultaneously. Besides meteorological factors such as current and forecasted temperature and its duration, wind velocity, humidity and cloud movement, protection decisions take into account such factors as the grove topography, variety of citrus grown and its use as fresh or processed product, market prices, previous crop damage, the grower's feeling on acceptable risk.

The geographical location, topology, the local micro-climate and other factors influence the need for and the selection of frost protection technology. Wind machines as well as heaters could be used independently as well as in combination. The use and function of both wind machines and heaters have already been described. The combined use of both of these methods is the most effective when the

temperatures are low, and/or inversions are very weak. The heaters provide additional heat which is then mixed throughout the grove by wind machines. Fewer heaters per acre are needed (approximately 15 to 25) in this combined system.

The exact level of freezing temperatures and their durations seems to be critical as far as the damages to the fruit and trees are concerned. It was reported [6] that leaf temperatures of 20°F and colder kills 100 percent of mature leaf tissue, while temperatures in the range of 20°-21°F can be expected to kill between 50 to 70 percent. A 22°F reading was found to kill only 5 percent, and temperatures in the range of 23°-24°F killed only 1 percent. Commercial growers tend to consider a hard freeze (one resulting in fruit loss and/or tree damage) to be characterized by temperatures equal to or less than 26°F for four or more hours (see Table 4.8). Therefore, as protection measures, wind machines are normally started when air temperature drops to 32°F and a duration of two or more hours at this or lower temperature is forecasted) and the air mixing started several degrees before critical

Table 4.8 Freezing Point For Citrus(°F)

	Degrees of at least two hours duration		Degrees of at least two hours duration
Small Green Oranges	28.5	Tender growth	27.0
Green oranges and grapefruit	27.5	Dark green growth	24.0
Half ripe orgs. & grapefruit	27.5	Buttons	24.0
Full ripe orgs. & grapefruit	27.0	Open bloom	30.0
Tangerines	29.5		

Source: The National Weather Service Office of State Climatology, Lakeland, Florida.

temperatures, damaging to fruit and leaves, are reached. The heaters are normally lit when the temperature readings are 26°F. As it was stated above, these temperatures are typical and actual decision points vary greatly among the growers.

Some varieties of citrus are more sensitive than others to freezing temperatures and therefore require greater protection. Another important consideration linked to citrus variety is the date of fruit maturity. Some varieties mature during the winter months and as a result, could be harvested immediately after a damaging frost. On the other hand, if the spring harvested varieties are damaged, the losses are more severe.

Finally the intended final use of the crop, whether it be for fresh fruit or processed concentrate, greatly influences long-term protection methods. Certain varieties of citrus, such as honey tangerines or temple oranges, are much more valuable as fresh fruit and, therefore, it is desirable to protect this valuable crop, because of the substantial difference in market price between the fresh fruit and processed product.

In addition to these influences, the grower in the short-run is always aware of fresh fruit spot prices, concentrate futures prices, his current debt situation and the price of fuel. These factors could be said to influence the growers' feelings on acceptable risk. What is unknown or at best uncertain to the grower during the crucial nightly decision making is the weather. In order to illustrate the interplay between what is known to the grower, i.e. location, variety, final use acceptable risk and the weather, an example of the decisions faced on a hypothetical frost night are presented in the following section.

4.2.5.2 An Example of Decision Strategy During a Hypothetical Frost Night

10:15 a.m.: NWS forecast for 24-28°F in grower's area. Negligible wind velocity, typical radiational night, grower alerts foremen to possibility of frost. Foremen check condition of wind machines, amount of fuel, ordering more if necessary. High school students hearing forecast begin calling to offer services, but grower tells them to wait until 7:00 p.m. for decision.

4:15 p.m. : NWS forecast confirms 10:15 a.m. forecast.

6:00-7:00 p.m.: Grower makes first major decision on whether to just keep the foremen around for running the wind machines or hire the labor crew for the night to fire heaters. Grower decides to have full complement and tells students to arrive at 10:00 p.m.

10:15 p.m.: NWS forecast is lowered slightly to 23-27°F in most areas, possible 21°F in cold spots. Temperature at 32° in cold spots. Our grower is "risk adverse," i.e., high quality tangerines for high grade fresh fruit, and consequently he orders the wind machines started in low lying areas. He frets about the high cost of the diesel fuel, but is assured by the thought of a higher market price if frost causes damage statewide.

11:00 p.m.: Temperature at 32°F in most groves, 27°F in the "coldspots." Grower, on receiving telephone temperature reports from key groves, orders all wind machines started. Though 32°F

will do no damage, he realizes that the wind machines have a greater efficiency in air mixture if started at 32°F or above. What bothers him most is his uncertainty over the duration of the temperature. For example, even if it drops below 26°F for an hour, he will suffer no damage. He finishes the hour by receiving a report that a cloud bank is moving towards his area, which would raise his temperatures. He wonders if he has wasted fuel by starting the machines so early.

12:00 Midnight: Cloud bank hasn't materialized. Temperature falls to 26°F in cold spots, but there is still a rumor of cloud movement. Grower is uncertain over temperature duration. Being uncertain he orders laborers to fire one-half of the heaters and turn off the wind machines in the cold spots. The remaining heaters are not used yet for two reasons: (1) if the temperature stays at 26°F or above only half would be needed anyway, (2) knowing that the heaters are good for only six hours of burning time, they are saved for the off-chance of an extended frost (usually the second night).

1:00 a.m.: Cold spot temperatures have been raised to 30°F by heaters, other groves at 32°F. So far so good.

2:00 a.m.: Cloud bank passes over briefly, temperatures rise and then rapidly fall. Grower was faced with uncertainty on whether to shut off heaters but decided to play it safe and leave heaters on.

3:00 a.m.: Temperatures falling rapidly in cold spots, at 24°F in some locations. Most groves holding at 30°F. Grower orders all heaters lit in colder groves. Since this is a radiational frost, he only has to protect until just after sunrise, and therefore he will have enough fuel for the remainder of the night. However, if this were an advective freeze, i.e., the blowing cold front, relative grove elevation would make little difference, and protection would have to be extended even after sunrise. At 3:00 a.m. and 24°F in this situation, the grower would probably decide to sacrifice the fruit to save his trees. He would keep the heaters lit until grove temperature reached 26°F, turn them off, let the temperature fall to 24°F again and then relight, continuing this until the danger was over. Though these temperatures and durations would damage the fruit, the break in duration 24-26 F, again and again would save his trees and furthermore save fuel, so that he could go until the late morning hours. A grower will always sacrifice the fruit to save the trees, since a damaged tree takes several years before a return to normal production. It must be noted that the dormancy state of the tree plays a crucial role here. If the trees were in the "green flush" stage, i.e., not dormant, a temperature of even 27°F might have damaged them.

3:30 a.m.: Temperature up to 29°F in cold spots, 30°F in most groves.

3:30-7:00 a.m.: Air temperatures remain fairly constant, as do grove temperatures. Grower continues with wind machines in higher

elevations, heaters in cold spots. Turns off wind machines and extinguishes heaters at 7:00 a.m.

8:00 a.m.: Laborers sent home. Orders foreman to assess fruit damage.

The frost protection process, i.e., the major decisions pertaining to the protection of fruit and trees, together with all information and major factors influencing these decisions is illustrated in Figure 4.12 which shows as the input the NWS broadcasts, and the readings of grove thermometers. Decisions are based on these inputs and the other factors; such as availability of frost protection technology (wind machines and/or heaters), risk adversity of growers, etc., as it was described in previous paragraphs. Due to the complexity of the whole problem, only the decisions due to the major factors during the frost protection process are shown (Figure 4.12).

4.2.5.3 Assessment of Damages and Losses Due to Frosts and Freezes

The growers attempt to estimate the extent of damage to fruit and trees due to frost or freezes soon after sunrise. The first indication of a possible damage to an orchard or its section are records of thermometer readings made during the preceding night. Fruit generally is damaged if exposed to temperature of 26°F or less for a period of four hours or more. Twigs and leaves are damaged if temperature is less than 22°F and the duration of exposure is four hours or more.

If there is an indication of cold temperature damage to fruit then visual inspection is made. The fruit is cut and inspected for damages to juice vesicles which lost their juice, collapsed and

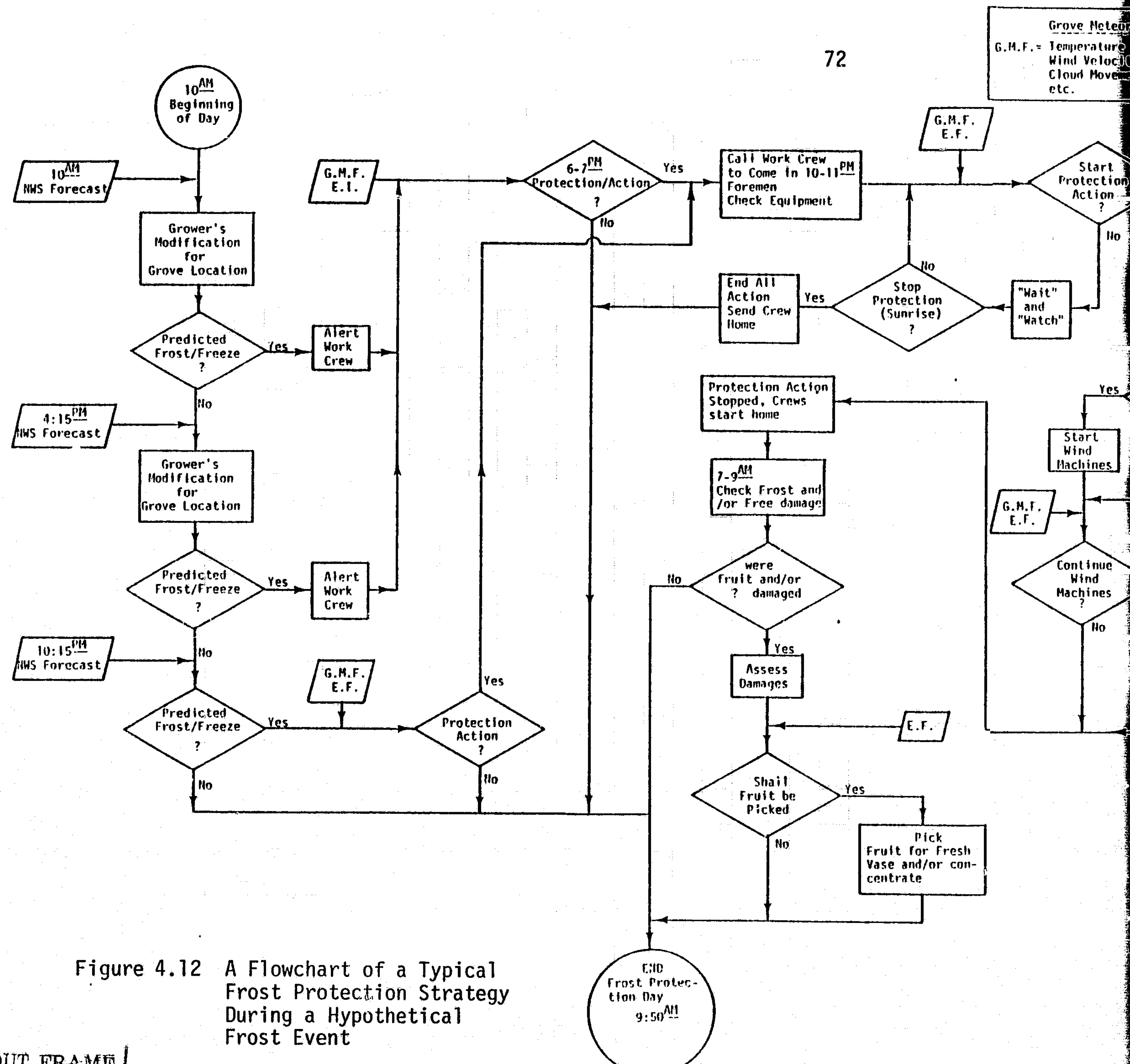
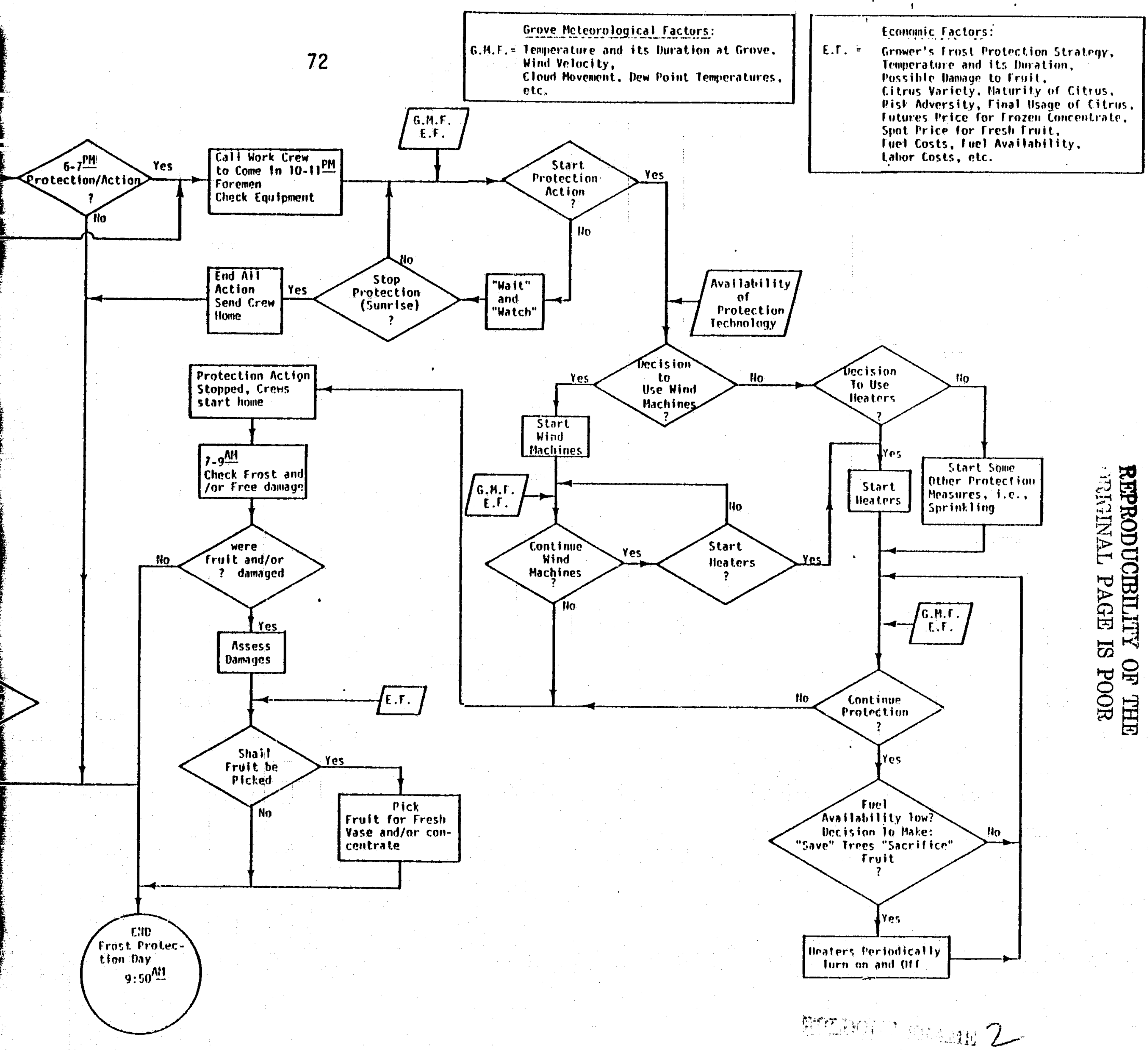


Figure 4.12 A Flowchart of a Typical Frost Protection Strategy During a Hypothetical Frost Event

FOLDOUT FRAME 1



Grove Meteorological Factors:
G.M.F. = Temperature and its Duration at Grove, Wind Velocity, Cloud Movement, Dew Point Temperatures, etc.
Economic Factors:
E.F. = Grower's Frost Protection Strategy, Temperature and its Duration, Possible Damage to Fruit, Citrus Variety, Maturity of Citrus, Risk Adversity, Final Usage of Citrus, Futures Price for Frozen Concentrate, Spot Price for Fresh Fruit, Fuel Costs, Fuel Availability, Labor Costs, etc.
6-7 PM Protection/Action ?
Yes
No
Call Work Crew to Come in 10-11 PM Foremen Check Equipment
G.M.F. E.F.
Start Protection Action ?
Yes
No
"Wait" and "Watch"
Stop Protection (Sunrise) ?
No
Yes
End All Action Send Crew Home
Availability of Protection Technology
Decision to Use Wind Machines ?
Yes
No
Start Wind Machines
Decision To Use Heaters ?
No
Yes
Start Heaters
Start Some Other Protection Measures, i.e., Sprinkling
G.M.F. E.F.
Continue Wind Machines ?
Yes
No
Start Heaters ?
No
Yes
G.M.F. E.F.
Continue Protection ?
No
Yes
Fuel Availability low? Decision To Make: "Save" Trees "Sacrifice" Fruit ?
No
Yes
Heaters Periodically Turn on and Off
Protection Action Stopped, Crews start home
7-9 AM Check Frost and /or Free damage
were fruit and/or ? damaged
No
Yes
Assess Damages
E.F.
Shall Fruit be Picked
Yes
No
Pick Fruit for Fresh Vase and/or concentrate
END Frost Protection Day 9:50 AM

became dry. These internal damages to fruit are visible from three to ten days after a freeze or a frost. Usually the fruit on the top of the tree is more susceptible to freezing temperature damage.

The variety of citrus plays an important role. If the damaged citrus achieved maturity and the damage is not extensive then it is picked as soon as possible and possibly packed as fresh fruit. The damage to fruit as far as the loss of juice is concerned is very small in the period of one to two weeks after a freeze. If the fruit is processed then the losses are almost negligible. It should be noted that the fruit must be mature and the ratio of sugar to acid must be satisfied according to the U.S.D.A. standards. The damaged fruit can decay more rapidly if temperatures after a freeze are relatively high.

Citrus which was not mature at the time of a freeze, such as Valencia oranges, must be left on trees until it becomes mature. During that period some fruit drops and some begin to dry. Healthy and severely damaged fruit are separated before processing. The losses as far as the content of juice is concerned could be up to 50 percent for the Valencia oranges (they achieve maturity in spring). The tangerines, which are valuable as fresh fruit and bring approximately $4.20/box, bring only about $1.92/box* when processed (the need for processed tangerines is limited). In the case of oranges, there is rather small difference between fresh and processed fruit, about 13 percent to 25 percent.

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*1976 prices as reported by Alcoma Packers, Inc., Lake Wales, Florida.

4.2.5.4 Frost Protection Cost

The cost of protecting fruit and/or citrus trees against freezing temperatures consists of: (a) capital outlay for the frost protection equipment, (b) cost of fuel for heaters and wind machines, and (c) cost of labor necessary to operate the equipment and to supervise and direct the frost protection operation.

As mentioned previously, the capital cost of wind machines is relatively high, compared to that of heaters, but the operating cost is low. The opposite is true for the heaters, i.e., low capital cost and high operating expenses. The evaluation of capital cost of various orchard heating systems is beyond the scope of this study.

Both the cost of fuel and cost of labor are directly linked to the cost of the frost protection process during any night for which the frost/freeze warning was issued. An example of decision strategy during a hypothetical frost night, presented in the preceding section, shows clearly that the "wait and watch" game played by citrus growers can be quite costly.

An estimate of the fuel requirements and labor costs for the citrus protection was made for Lake and Orange Counties [7] and the results were extrapolated for the whole state of Florida. The following paragraphs and Table 4.9 are summarized from Reference 7 .

A survey of 65 organizations and growers in Lake and Orange Counties showed that only 12 did not protect their citrus and it was assumed that 70 percent of all protected citrus acreage was accounted for. The following additional assumptions were made:

a. average number of heaters per acre is 40,

b. fuel consumption of heaters is 1 gallon/hour/heater,

c. average number of wind machines is one per ten acres,

d. 75 percent of wind machines are run by gasoline engines,

e. fuel consumption of wind machines is 5 gallons/hour for gasoline engines and 7.5 gallons/hour for diesel engines, and

f. fuel for operating service vehicles used in lighting and refueling the heaters is not included.

Tables 4.9 and 4.10 show the total protected acreage, fuel requirements per hour, total fuel requirements, the fuel cost and the labor cost for a typical winter season consisting of one to six nights requiring protection (each six hours). The estimate for the whole state is that approximately $5,000,000 worth of fuel is consumed in an average night to protect the citrus crop.

The labor cost is relatively small compared to the cost of fuel. It was estimated [7] that the average labor cost is $0.42/acre/hour, and includes the time of no action during the "wait and watch" game. Since 29,099 acres of citrus are protected in Lake and Orange Counties, the labor cost is $12,222 per hour. The estimated labor cost for the whole state is therefore on the order of $36,666 per hour of cold protection. Though the average <u>hourly</u> labor cost is only 6 percent of the total hourly protection cost, it must be kept in mind that the seasonal labor cost constitutes a much higher percentage of the total seasonal protection costs. This is because growers frequently are forced to play the "wait and watch" game whereby the entire protection crew is kept in readiness throughout the groves but the temperatures and durations are such that no protection is needed. The hourly protection costs cited in Table 4.10 assume that all heaters and wind machines are in full operation. It is more likely the case that the crew will work for six hours

Table 4.9 Cold Protection - Data

		Lake-Orange Area	State of Florida
Total Acreage		192,700	791,000
Protected Acreage		29,099	87,300
Protected Acreage - % of Total Acreage		15.1	15.1
Protection by Heaters - Acreage		15,176	45,528
Protection by Heaters - % of Total Acreage		7.9	7.9
Protection by Wind Machines - Acreage		13,923	41,769
Protection by Wind Machines - % of Total Acreage		7.2	7.2
Fuel Consumption (gallons/hour of protection)	Diesel	609,650	1,828,950
	Gasoline	5,220	15,660
Estimated Cost	Diesel Fuel ($/gallon)	0.45	0.45
	Gasoline Fuel ($/gallon)	0.55	0.55
	Labor ($/acre/hour)	0.42	0.42

Source: Jackson, J.L., Cost of Cold Protection, Florida Cooperative Extension Service, University of Florida, IFAS, 1976.

Table 4.10 Cold Protection - Costs

Number of Nights (fuel: 6 hrs/night) (labor: 8 hrs/night)	Lake-Orange Area					State of Florida				
	Diesel Fuel (Million gallons)	Gasoline Fuel (Thousand gallons)	Cost of Fuel (Million $)	Labor Cost (Thousand $)	Total Cost (Million $)	Diesel Fuel (Million gallons)	Gasoline Fuel (Thousand gallons)	Cost of Fuel (Million $)	Labor Cost (Thousand $)	Total Cost (Million $)
1	3.66	31.3	1.66	97.8	1.76	10.97	93.9	4.99	293.4	5.28
2	7.32	62.6	3.33	195.5	3.52	21.95	187.8	9.98	586.8	10.56
3	10.97	94.0	4.99	293.4	5.28	32.92	282.0	14.97	880.2	15.85
4	14.63	125.3	6.65	391.2	7.04	43.89	375.9	19.96	1,173.6	21.13
5	18.29	156.6	8.32	489.0	8.81	54.87	469.8	24.95	1,467.0	26.42
6	21.95	187.9	9.98	568.8	10.57	65.84	563.7	29.94	1,760.4	31.70

and the wind machines and heaters will be used for only two hours. The frequent occurrence of a full crew and little actual frost protection is a direct result of the grower's uncertainty about the weather, especially on those nights where the temperature remains in the 28-32°F range. Since it is hoped that the SMS improved forecasts can reduce this uncertainty, reduction in labor costs should be a prime SMS benefit area.

4.2.6 Citrus Industry Benefits Due to Improvements in Forecast Accuracy

4.2.6.1 The Improved Weather Forecast and its Impact

It is anticipated that the utilization of satellite measured temperature data will result in improved accuracy of weather forecasts and knowledge of actual temperature distributions across the state of Florida. It is expected that this, in turn, will have a direct impact on improving frost protection decisions with reduced protection costs and crop losses and lead to improved marketing strategies. Currently, weather forecast accuracy is dependent, to a large extent, upon the forecaster's experience and knowledge of local conditions. To a large extent the satellite data, together with computer forecasting models, will help to remove the human factor from weather forecasting and therefore make the forecast independent of forecaster's capability.

At present all data available to a meteorologist are in discrete sets be it from meteorological sounding or temperature readings from ground stations. Approximate temperature maps are then generated. These are then combined in the forecaster's mind, based purely on his experience, into a more or less continuous picture in time and space,

reflecting also all other factors playing an important role in this highly subjective weather forecast. It requires a number of years experience to master all of the intricate peculiarities in topography and other factors to make effective and accurate forecasts. Unfortunately, many of the experienced meteorologists are retiring from NWS and the younger forecasters do not, in some cases, have the necessary experience. The satellite data would provide a continuous map of meteorological events in time as well as in space, and thus would be a decisive step in minimizing the subjectivity of weather forecasts. Especially in conjunction with the temperature forecast model being developed by the University of Florida the forecast capability may become more independent of forecasters' skills.

The almost immediate result of this improved data base for forecasting would be in narrowing the forecasted temperature range from 4°F to 2 F$^{\circ}$[8]. This narrower range of temperatures would be extremely helpful during "wait and watch" nights when the forecasted temperature is in a borderline region, and the growers must decide either to take a protective measure or not to take one. In another example, assuming that temperatures were changing to a dangerous level, the timely knowledge of cloud movement, the size, depth and velocity over a grower's area, would enable the grower to hold off firing the heaters, which the grower would have to do otherwise.

4.2.6.2 Benefit of Statewide Frost/Freeze Damage Data

Satellite temperature data may result in improved timely knowledge of actual temperature distributions which occurred across the state. This knowledge may lead to another important benefit area,

i.e., improved damage assessment of fruit and trees due to frosts and freezes. At the present time this assessment of damages is most beneficial to the large growers with groves throughout the state citrus growing regions.

Some very large growers who primarily process their product can interchange the orchards designated for fresh fruit in case of frost damage with some of those designated for the processed fruit, and thus minimize their losses. The fruit suspected of being damaged is picked up immediately following the frost or freeze and is then transported to the processing plant. As a result of this quick action, there may be little or no loss in the juice content.

The large growers also try to estimate the potential damages due to freezing temperatures on the citrus industry throughout the state. This estimate then becomes an important factor in their market strategy as far as the pricing of various varieties of fruit is concerned. The damage assessments for the whole Florida citrus industry, which could be one of the benefits of the satellite measured data, would help in the statewide citrus crop prediction and also improve the statewide marketing strategy.

The price fluctuation of citrus products and the influence of the losses of the fruit due to frosts and freezes is reflected in the quotations for Florida frozen orange concentrate (See Table 4.11). There was a 60 percent increase in price immediately following the 1962 freeze (December 12-14, 1962). The high prices prevailed in the following two years as well and grew even higher when it became evident that the

Table 4.11 Quotations for Florida Orange Concentrate
F.O.B. Non-Advertised Brands Only
(Per dozen 6 ounce cans)

Year	F.O.B. Price ($)		Date of Change in Price
1957	1.25	To	May 6
	1.00	"	July 4
	1.15	"	July 29
	1.25	"	Dec. 16
	1.50	"	Dec. 23
	1.75	"	-------
1958	1.75	"	Feb. 3
	2.00	"	Mar. 23
	2.25	"	-------
1959	2.25	"	Jan. 3
	1.75	"	May 4
	2.00	"	Nov. 3
	1.50	"	-------
1960	1.50	"	Aug. 22
	1.65	"	-------
1961	1.65	"	Jan. 2
	2.00	"	Apr. 1
	1.75	"	-------
1962	1.75	"	Jan. 15
	1.50	"	Mar. 7
	1.35	"	Dec. 10
	1.25	"	Dec. 12
	2.00	"	-------
1963	2.00	"	Jan. 14
	2.05	"	Feb. 23
	2.30	"	Mar. 22
	2.55	"	-------
1964	2.55	"	Apr. 18
	2.30	"	-------
1965	2.30	"	Jan. 15
	1.85	"	Apr. 16
	1.55	"	Dec. 27
	1.40	"	-------
1966	1.40	"	Feb. 7
	1.60	"	Apr. 18
	1.75	"	-------
1957	1.75	To	Jan. 16
	1.25	"	Feb. 20
	1.00	"	Mar. 20
	1.10	"	Apr. 10
	1.20	"	June 26
	1.25	"	Oct. 9
	1.43	"	Nov. 7
	1.47	"	--------
1968	1.47	"	Jan. 13
	1.55	"	Mar. 30
	1.65	"	Aug. 5
	1.75	"	--------
1969	1.75	"	Jan. 20
	1.85	"	Feb. 10
	2.00	"	May 12
	1.75	"	--------
1970	1.75	"	Feb. 16
	1.53	"	June 21
	1.45	"	Aug. 23
	1.53	"	Sept. 28
	1.38	"	--------
1971	1.38	"	Feb. 20
	1.53	"	Apr. 24
	1.68	"	May 15
	1.78	"	July 17
	1.88	"	--------
1972	1.88	"	--------
1973	1.88	"	Apr. 21
	1.61	"	Sept. 22
	1.88	"	Mar. 9
1974	1.75	"	May 6
	1.88	"	July 8
	1.63	"	Aug. 26
	1.88	"	Sept. 21
	1.95	"	Sept. 28
	1.70	"	Nov. 23
1975	1.95	"	Jan. 18
	2.10	"	Mar. 8
	1.85	"	Apr. 12
	2.10	"	July 5
	1.97	"	Aug. 30
	2.10	"	--------

Source: Compiled by Florida Citrus Mutual from F.O.B. quotations of various processors.

1962 freeze had very negative impact on the citrus production in those years.

4.2.7 Historic Data Availability

In the discussion above, both the need for improved frost forecasts and the possible impact of the improved forecasts on the grower's decision process have been outlined. In order to proceed onto the next step, the design of an experiment that will measure the reductions in costs of frost protection due to improved forecasts, it is first necessary to evaluate the general availability of historic economic and meteorlogical data. The availability and existence of historical records will to a large degree dictate much of the experiment methodology.

4.2.7.1 Availability of Historic Economic Data

There are essentially two types of historic economic data which are of interest to the design and conduct of the ASVT experiment. The first are the nightly costs of frost protection and dollar value of frost damage as kept by individual growers. The second type of data includes such aggregate statistics as county and statewide frost losses, fresh fruit and concentrate spot prices, concentrate futures prices, heater, and wind machine fuel prices, labor costs and the like.

It has been determined that very few growers keep detailed records of their nightly protection costs. This determination was made by contacting a number of growers who were likely to keep some type of nightly record. In addition to the five growers interviewed during a field trip to Florida, five more growers were suggested by

Dr. Jim T. Griffiths of Florida Citrus Mutual as being probable candidates. Only one grower, a cooperative association, was found to keep any type of consistant nightly records.

These records consisted of the:

1. regional forecast,
2. hourly temperature recordings for each grove,
3. the time and temperature at which the heaters were lit or wind machines were started in each grove, and
4. the time and the temperature the same were extinguished or shut off.

The records of a sample night, January 28, 1976, of the frost protection operations of the Haines City Co-operative are shown in Table 4.12. The numbers in the far left column refer to the various groves and the rows associated with each grove give the nightly progression of air temperature over fairly random time intervals. If a particular time and temperature box is outlined with a squiggly line, it means that the wind machines for that grove were turned on at that time and temperature. A solid line about the box would indicate the same for the heaters in the grove. The time and temperature at which the heater or wind machine was put down is indicated by the word "off" in the appropriate box. Given such records and other associated data it is possible to compute the nightly cost of frost protection at the Haines City Co-operative. The needed additional information for computation would be such data as number of heaters and wind machines in each grove, fuel consumption per hour, the cost of fuel, and manpower and wage rates per hour per wind machine and heater. As mentioned

Table 4.12: Portion of nightly Frost Protection Records as Kept by Haines City Co-operative, Haines City Florida, Night of January 28, 1976.

Grove No.	Time (a.m.), Temperature (°F)* and Action Taken					
19	12:00 30°	2:40 35°	4:25 34°	8:00 off		
44	12:00 33° 29° 28°	1:20 31° 29° 32°	3:25 30½ 30 32	5:20 29 27 31	7:55 32 32 32 off	
25	12:00 29P 30NW 30	1:00 30° 30° 30°	3:00 33 30 28	8:00 off		
507	12:15 29° 30°	3:00 33° 34°	4:30 33° 34°	7:30 off		
42	12:15 26° 27°	1:25 29° 30½	3:25 30° 29°	5:20 29W 31E	8:00 32 32½ off	
247	12:15 30°	1:15 34°	3:35 33°	4:55 34°	6:15 33°	8:00 34 off
26	12:15 31°	1:30 29½	2:50 30½	5:05 33½	5:40 29½	8.00 35 off
480	12:25 34° 34°	1:25 33 33°	3:15 33° 33°	4:50 33 33½	6:15 32° 32°	
172	12:30 38°	1:45 32°	3:40 32°	5:00 32½	6:10 32°	
148	12:30 29° 28½	2:10 29S 26½	4:05 32 25°	6:30 27 24°	8:20 off	
295	12:35 33°	2:40 33°	4:45 32°			
20	12:35 32°	1:40 34°	3:35 34°	5:10 33°	6:10 32°	
138	12:45 31°	1:50 29°	3:50 34°	6:20 34°	8:10 34° off	

*In the case of protective action, the indicated temperatures have been perturbed by the action and do not indicate the temperature that would have resulted if the action had not been taken.

above, the grower who maintained these records was employed by a co-operative association. In a "co-op", growers are paid by the actual owners of the groves to oversee, protect and harvest their groves. Because the grower must justify incurred expenses to the owner it was felt that most co-ops would keep detailed records. Unfortunately, after contacting several large co-ops throughout the state it was determined that Haines City was the exception rather than the rule. Consequently there exist detailed nightly records for only 400 acres (Haines City protected acreage) of the approximately 80,000 protected acres in the State of Florida (.5 percent).

It was also determined that detailed records on frost losses for both tree and fruit damages are not kept by the individual growers. At first it was hoped that Federal Crop Insurance Corporation (FCIC) records would provide the needed information, but discussions with citrus industry specialists indicated that very few growers use the insurance program. It appears that the premium payments are not worth the present value of potential compensation given the low frequency of severe frost events in recent years.

Fortunately, aggregate economic data are easier to obtain and in many cases summary statistics are published and widely available. For example, Florida Citrus Mutual and the Growers Administrative Committee publish statistical reports on:

1. crop size, including the annual production totals for Florida, California, Texas, and the world, by citrus variety

2. acreage by variety in Florida, California, and total U.S.

3. crop utilization, i.e. fresh fruit, concentrate, sections and salad

4. box yield per tree, by age group, by variety

5. processed and fresh crop movements, i.e. weekly movements of concentrate, carry overs, etc.

6. spot and futures prices for concentrate, spot fresh prices, Free on Board (FOB), production and marketing costs, and on-tree prices.

Additionally, the Florida Crop and Livestock Service publishes an annual report entitled Florida Agricultural Statistics, which is essentially a detailed citrus tree inventory. The inventory lists the commercial acreage of each county by citrus variety and the acreage planted annually since 1936.

4.2.7.2 Availability of Historic Meteorological Data

There are three types of historic meteorological data which would be of interest to the ASVT experiment. These are: (1) individual grove temperature and durations as kept by growers, (2) the four times daily National Weather Service (NWS) forecasts for each zone, and (3) the actual recorded temperature and durations as recorded by the NWS throughout the state. Outside of the temperature records as kept by the Haines City Co-operative discussed above, no evidence of individual historical grove records has been found. Even if most growers kept comparable records an accuracy problem would exist since many of the individual readings on the cold nights would be perturbed by frost protection actions. A thermometer anywhere near a heater for example would not measure the true air temperature. Further discussion on this topic will be found in Section 4.3.5.1 under the topic of control and grove temperature correlation. Records of NWS

forecasts for each of the 23 zones in Florida are available for at least 10 years, but have not been published. Fortunately, Dr. Jim Georg of the Agricultural Weather Service in Lakeland has kept the teletype forecasts bound in his office and has kindly offered to lend them to ECON for the experiment. An example of these forecasts can be found in Section 4.2.4 of this report.

The Federal-State Agricultural Weather Service has also kept comprehensive temperature and duration records for approximately 300 stations since 1937, and annual reports have been published for each weather forecast zone in peninsular Florida. A map of Florida illustrating the 23 forecast zones can be found in Section 4.2.4. It must be noted here that as of October 1, 1972 the NWS changed their areal forecast system somewhat such that the old forecast "districts" do not exactly correspond geographically to the new forecast zones. (See Section 4.2.4). This change should not cause any difficulty since if the historical forecasts are used they will be needed from only 1974 to the present (See Section 4.3.5.1). The published temperature reports include;

1. the minimum recorded temperature for each station for all cold nights, (a cold night is marked by an occurance of a 36^{o} reading or below),

2. temperature durations in hours and tenths of hours for all cold nights,

3. the number of times each station experienced 32^{o} or lower, and

4. the relative elevation of each recording station.

Table 4.13 shows the manner in which the data is originally encoded before compilation for zone 14 (Polk County). The four digit number on the far left hand side is the numerical station identifier which is followed by the name of each station. The "Min." column contains the nightly minimum temperatures and the durations are listed in the remaining columns. The asterisks denote interpolated data.

4.3 Experiment Concept

4.3.1 Overview

The Synchronous Meteorological Satellite (SMS) currently in orbit is furnishing temperature and other data to ground receiving stations. The National Weather Service plans to receive much of this data at Ruskin, Florida and utilizing computer and display equipment which it is planned will be installed at Ruskin in the near future, together with temperature forecast models under development at the University of Florida, will be capable of generating high resolution spatial and temporal short-term temperature forecasts. Thus, actual temperature distributions of 4n.mi. spatial resolution and .5 degrees centigrade temperature resolution will be observed hourly across the state of Florida and incorporated into the University of Florida forecast models. These forecasts will then be utilized, in conjunction with other data available to the National Weather Service, in the determination of the meteorological forecasts (as described in Section 4.2.4) provided by the National Weather Service to the citrus growers.

It is anticipated that the citrus growers will, as they have in the past, utilize the temperature forecasts in their planning and

Table 4.13: Sample Encoding Sheet for Temperature and Duration Data as Used by Federal-State Agricultural Service; January 18, 1976 Zone 14, Polk County

Location	Min. Temp.	Hours at and below: 32°F	30°F	28°F	26°F	24°F	Below 24°F
2625 31POLK CITY	24	5.3	3.8	2.9	1.0	0.1	
2627 07DAVENPORT	29	5.7	1.3				
2726 28LK ALFRED	31	1.3					
2827-C12LK HAMILTON	28	7.3	2.5	0.5			
2827-D04PRINE	31	2.0					
2924-A15HIGHLD CITY	32	0.5					
2928 32MAMMOTH	28	8.5	4.7	0.8			
3026 07LK GARFIELD	29	3.8	0.6				
3028-B01TEMPLETON	31	2.2					
3126- A06LK GFLD NSY	29	1.3	0.7				
3227 24FROSTPROOF W.	29	5.2	0.5				
3228-C04FROSTPROOF	32	0.1					
3228-A31HIGHLD LKS	*31	2.0					
3328 12AVON PARK	31	0.6					
3329 30PINECREST	32	1.8					
3528-A08CHOCOLATE HILL	26	8.2	6.3	4.0	0.8		
3629-A10LK PLACID	**30	4.0	2.0				
3830-A18HICORIA	22	8.5	5.7	4.0	2.4	1.7	0.2

Asterisks denote extrapolated temperature points.

decisions pertaining to frost protection. As has been discussed previously (Section 4.2.6) SMS temperature data may result in improved temperature forecasts which may in turn result in both reduced citrus crop protection costs and reduced citrus crop losses. The reduced protection costs will arise from better decisions with regard to when frost protection is necessary, when protective action should originate and when it should be terminated. Crop loss reduction may result from improved temperature forecasts whereby frost occurrences are forecast more accurately (i.e., the probability of not predicting a frost which in reality does occur--miss probability--is reduced) and adequate frost protection measures taken. It should be noted that crop losses may be reduced both by reducing the miss probability and forecasting the magnitude and duration of an anticipated frost more accurately.

The SMS temperature data can also play a role in frost damage assessment by providing a current comprehensive record of temperatures which occurred throughout the State of Florida. These temperature measurements may result in improved decisions concerning the harvesting and processing of frost damaged crops. The historical temperature measurements may also play a role in harvesting and pricing decisions whereby growers have more information on the status of other citrus growers' crops as impacted by actual temperature conditions.

The economic experiment portion of the ASVT is being planned to measure the economic benefits which might result from improved frost forecasting and associated with reduced citrus crop protection costs and reduced crop losses due to frost incurred damage. The experiment should also yield estimates of crop loss reductions which may result

from improved knowledge of actual temperatures which occurred and their impact on harvesting and processing decisions. The experiment, because of the very limited number of frost seasons which can realistically be considered (i.e., the sampling problem) is not being planned to provide experimental verification data of the economic benefits which may result from better knowledge of actual temperature distributions throughout the State of Florida.

It should be noted that the objective of the Florida ASVT is actually twofold, namely (a) to demonstrate the impact of satellite derived data upon the accuracy and timeliness of frost forecasts to Florida citrus growers, and (b) to measure the resulting economic benefits. The experiment concepts to be discussed in the following pages are concerned only with the measurement of the economic and related (i.e., fuel conservation) benefits.

In order to measure the economic benefits of improved information (i.e., the SMS temperature data), it is necessary to establish and then compare the costs and losses which would result with and without the improved information. This implies establishing two separate groups, namely a test group (the "haves") and a control group (the "have-nots"). Since the National Weather Service does not at this time contemplate changing the information distribution network and since current meteorologic forecasts are available to all citrus growers, it is not possible to establish control and test groups simultaneously in the State of Florida. This implies that the necessary isolation between the citrus growers comprising the control and test

groups needs to be established through geographic and/or time displacement. Since geographic displacement within the State of Florida is not possible, it is theoretically possible to establish a control group outside of Florida. Serious doubt as to the credibility of a control group outside of Florida has been raised by representatives of the Florida citrus growers, the NWS, the USDA County Extension Agents and the University of Florida. Since it was deemed important to develop credible results, the idea of a control group outside the State of Florida has been ruled out. Thus it is necessary to establish the control group by time displacement. The time displacement can be either (or both) backward in time or forward in time--the former relying on historical data and the latter relying on at least a one frost season delay in the utilization of SMS data for frost forecast improvement on an operational basis.

The use of historical data for the control group appears to be possible but highly risky. Numerous discussions with citrus growers in Florida have indicated that there is in general a lack of detailed data which is necessary to establish the pertinent costs and losses. However, a single large citrus grower co-operative was found which kept detailed records of weather occurrences and protective actions taken by individual groves (approximatley 400 protected acres are operated by this co-operative). From discussion with the management of the co-operative, it appears that the necessary cost and loss data might be forthcoming. It also appears that the NWS forecast data and actual temperature occurrence data are available. Thus it appears that the cost per event*

*See Section 4.3.2 for a discussion of "events".

per acre per grove type may be available. The risk associated with this approach is due to the limited number of years of history (only at most the last two frost seasons can be considered because of the impact of fuel price changes on the decision process) combined with a single sample of grower type with its specific operational, decision and business practices, and the possibility that when pressed for detailed grower cost and loss data, they may not be available to the degree of accuracy required.

It is therefore highly desirable to establish a control group consisting of a number of growers during the 1976-77 frost season and using historical records, as appropriate, to increase the sample size. The same growers which participate as part of the control group could thence participate in the test group during the 1977-78 and other future frost seasons. The Florida citrus crop frost forecasting experiment plan described in the following pages is predicated upon this approach.

The basic concept of the experiment is as follows (refer to Figure 4.13). During the 1976-77 frost season, the National Weather Service will provide frost and temperature forecasts and measurements to the citrus growers in a business as usual fashion--i.e., without the benefit of SMS temperature data, without the University of Florida forecasting models currently under development and without the computers and display equipment required to operate on the SMS data with the University of Florida models. During the 1976-77 frost season, it will be necessary for a selected set of citrus growers to provide data

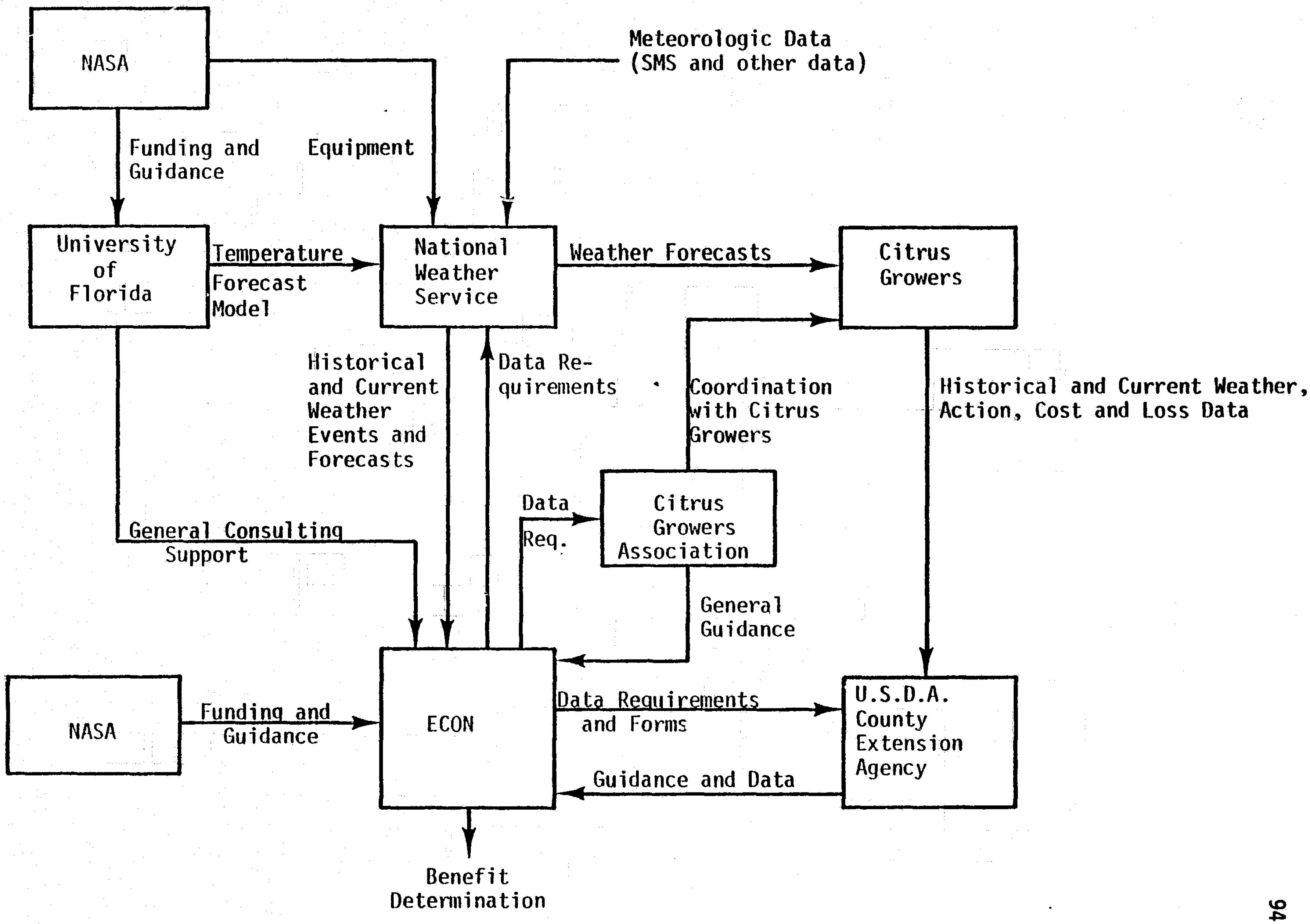


Figure 4.13 Participants in the Florida ASVT

on actual temperatures, decisions made and actions taken. It will also be necessary for these growers to provide cost and loss related data. It will be necessary for the National Weather Service to provide data pertaining to temperature forecasts and actual observed temperatures. This data will be analyzed by ECON and the average cost and loss per event determined for the control group. ECON will also try to add to the sample size of the control group by working with growers who have maintained detailed historical records and with the National Weather Service historical data.

The same processes as performed during the 1976-77 frost season will be repeated during the 1977-78, 1978-79 and possibly following frost seasons. It is assumed that the SMS data, together with the University of Florida forecasting models, and improved computer and data display equipment, will be used by the National Weather Service starting with the 1977-78 frost season. It is felt that a minimum of two frost seasons of test group experience are required since it is likely that during the first season, growers and forecasters will be learning to adapt their decisions and actions to the improved information. Thus, it is likely that the 1977-78 frost season will be a transient one with the steady-state reached by the 1978-79 frost season.

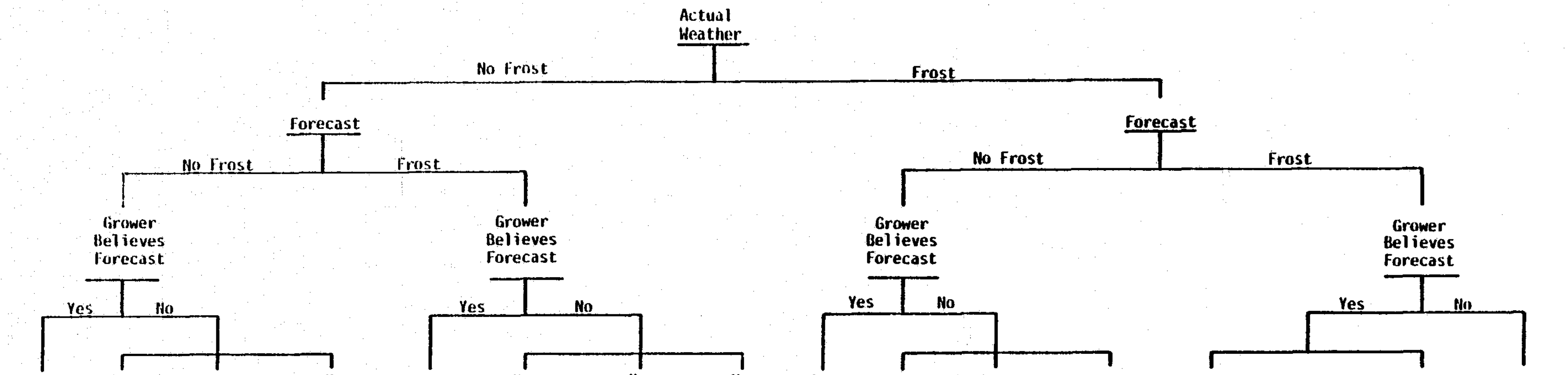
The data provided by the test group will, as in the case of the control group, yield average cost and loss per event. As described in following pages, both the control group and the test group cost and loss per event data can be extrapolated to the annual cost and loss for

the Florida citrus industry for an average frost season. The difference between the control group and test group annual costs and losses extrapolated to an average frost season will provide an estimate of the average annual benefits which are a direct result of the improved information. These benefits will include the reduction of citrus grower frost protection costs and the reduction of crop losses which are the result of improved decisions which are due to the improved information. The benefit assessment will not include, because of the limited number of frost seasons and hence data samples, those benefits which are the result of better marketing decisions made possible by the improved temperature distribution knowledge provided by the SMS data.

4.3.2 Methodology

The overall concept of the experiment has been established as well as the need for control and test groups. A gross framework of the experiment to be performed with the Florida citrus growers is now established with further details given in following sections.

Figure 4.14 illustrates, in a simplified form, sixteen various events which are of concern to the experimenter in terms of actual weather conditions, NWS frost forecast, grower belief of the NWS forecast and grower actions. The actions which are possible on the part of the citrus grower are classed as protect or no-protect actions. Protective action implies the utilization of heating devices and/or wind machines. No protection implies the lack of utilization of heating devices and/or wind machines. The no-protection events are subdivided so that no-protect situations which arise from either too short notice to take



ACTION	No Protect	Protect	No Protect (too short notice)	No Protect (other constraints)	Protect	No Protect (too short notice)	No Protect (other constraints)	No Protect	No Protect	Protect	No Protect (too short notice)	No Protect (other constraints)	Protect	No Protect (too short notice)	No Protect (other constraints)	No Protect
COST	0	C_2	0	-	C_9	0	-	0	0	C_6	C_7	-	C_{13}	C_{14}	-	0
LOSS	0	0	0	-	0	0	-	0	L_5	L_6	L_7	-	L_{13}	L_{14}	L_{15}	L_{16}
NO. OF DAYS OUT OF N	N_1	N_2	N_3	N_4	N_9	N_{10}	N_{11}	N_{12}	N_5	N_6	N_7	N_8	N_{13}	N_{14}	N_{15}	N_{16}
I	1	2	3	4	9	10	11	12	5	6	7	8	13	14	15	16

Figure 4.14 Event Descriptions

protective action or other constraints (for example, inoperative equipment) are clearly delineated. For each of the events or situations there are costs and losses. The only costs of concern are those associated with frost protection, C_I, and losses which result from inadequate or lack of protection, L_I. N_I represents the number of days out of N that the I^{th} event has occurred during the frost season. Sections 4.3.3 and 4.3.4 deal with details of the mechanism whereby the citrus grower costs and losses can be determined, respectively. For example, consider event I=13. This represents the situation where frost actually occurred which was forecast, and the grower believed the forecast and protected his grove. Protection costs and losses (possibly zero) were incurred which were dependent upon the severity of the frost. For the case, I=9, where frost did not occur but was forecast (i.e., false alarm) and the grower believed the forecast, protective action was taken and protection costs incurred but no crop losses occurred.

The information illustrated in Figure 4.14 is rearranged and presented in Table 4.14 in a manner which makes clear the correct forecast, miss and false alarm events and correct and incorrect decisions. A miss is defined as the occurrence of frost given a forecast for no frost. A false alarm is defined as the lack of occurrence of frost given a forecast for frost. The determination of a number of pertinent forecast and decision statistics is illustrated in Table 4.15.

Note that all of the ID, C, L and N variables have been subscripted by I, the event. This has been done for the sake of simplification. In general, the following subscripting notation will be employed:

Table 4.14 Weather Event/Forecast and Decision Array

Weather Forecast	Actual Weather	
	Frost	No Frost
Frost - ID_1 (I=9 → 16) Believed-ID_7 (I=9,10,11,13,14,15) Not Believed-ID_8 (I=12,16)	Correct Forecast(c)-ID_3 (I=13 → 16) Correct Decision(c) (I=13,14,15*) Incorrect Decision(m) (I=16)	False Alarm(fa) - ID_5 (I=9 → 12) Incorrect Decision(fa) (I=9,10,11*) Correct Decision(c) (I=12)
No Frost - ID_2 (I=1 → 8) Believed-ID_9 (I=1, 5) Not Believed-ID_{10} (I=2,3,4,10,11,12)	Miss(m) - ID_4 (I=5 → 8) Incorrect Decision(m) (I=5) Correct Decision(c) (I=6,7,8*)	Correct Forecast(c)-ID_6 (I=1 → 4) Correct Decision(c) (I=1) Incorrect Decision(fa) (I=2,3,4*)

*Decisions which are constrained by other factors.
Note: c = correct, m = miss, fa = false alarm.

Table 4.15 Typical Forecast and Decision Statistics

ID_1 = Number of days of forecast for frost = $ID_3 + ID_5$

ID_2 = Number of days of forecasts for no frost = $ID_4 + ID_6$

ID_3 = Number of days of forecast for frost given frost occurred =

$$\sum_{I=13}^{16} N_I$$

ID_4 = Number of days of forecast for no frost given frost occurred =

$$\sum_{I=5}^{8} N_I$$

ID_5 = Number of days of forecast for frost given no frost occurred =

$$\sum_{I=9}^{12} N_I$$

ID_6 = Number of days of forecast for no frost given no frost occurred =

$$\sum_{I=1}^{4} N_I$$

ID_7 = Number of days of frost forecast which are believed = $ID_1 - ID_8$

ID_8 = Number of days of frost forecast which are not believed = $N_{12}+N_{16}$

ID_9 = Number of days of forecast for no frost which are believed =

$N_1 + N_5$

ID_{10} = Number of days of forecast for no frost which are not believed =

$ID_2 - ID_9$

MD = Number of incorrect decision (miss) days = $N_5 + N_{16}$

FAD = Number of incorrect decision (false alarm) days =

$N_2 + N_3 + N_4 + N_9 + N_{10} + N_{11}$

CD = Number of correct decision days = $N_1 + N_6 + N_7 + N_8 + N_{12} + N_{13} + N_{14} + N_{15}$

I = event type

J = citrus grower type

K = citrus grower identification (i.e., grove designation)

M = degree-hour category

D = day

Some further comments are necessary with respect to the subscripting. I, the event type, is as described in Figure 4.14. J is an index which represents citrus grower type where geographic, operating practices, crop differences, etc., are taken into account. Thus each participating citrus grower, at the individual grove level, will fall into one of the J types. K is an index which represents the identity of the groves within the J classification. The $K^{\underline{th}}$ grove represents the smallest geographic sector for which data is available and/or the largest sector for which constant weather, decision, cost and loss characteristics exist. It is assumed that there will be a large number (yet to be determined) of growers who will participate in the experiment and provide data. These growers, indicated by the K subscript, may be classified by type and grouped accordingly. In other words, the $K^{\underline{th}}$ grower may be specified to belong to the $J^{\underline{th}}$ type as indicated in Figure 4.15.

It is important to note that the current weather forecast service predicts temperatures for the coldest points within large regions. Thus, growers who are rather far removed from these locations are forced to modify the NWS forecast based upon their particular geographic location relative to the forecast location. Since the SMS/GOES data will provide temperature measurements with 4 n. mi. resolution and forecasts may be available with this resolution, the grower's closeness

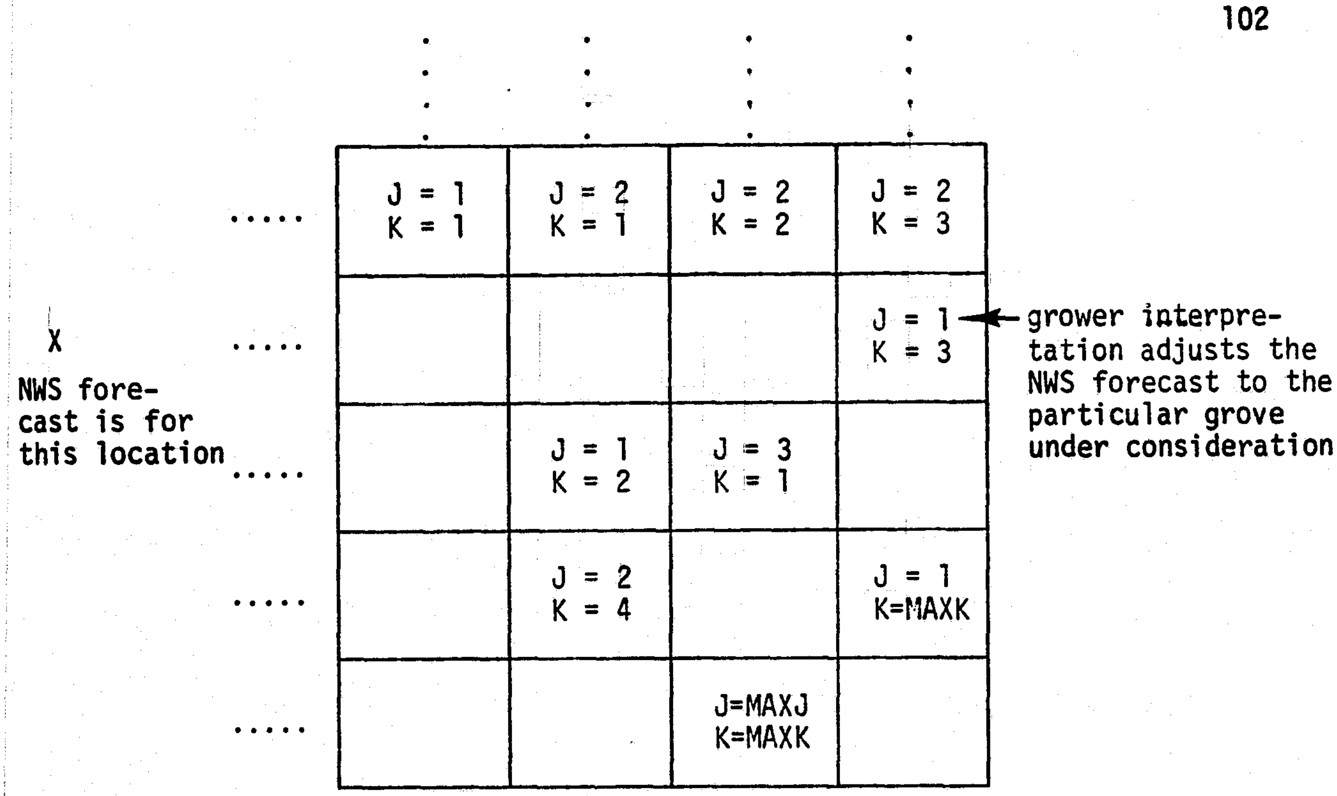


Figure 4.15 Grower Designation

to the forecast location may change causing a change in the grower's "modification" of the forecast.

For the purpose of this analysis, it is necessary to develop a reference frame which can be utilized to compare frost protection and loss data obtained during different frost seasons where the average frost intensity and/or duration may vary from season to season. For this purpose, the M index is employed and corresponds to specific ranges of frost intensity and duration, measured in terms of degree-hours per day below a baseline temperature (for example, 28 F). For those days when no frost occurs, the degree-hour measure is set to zero.

Therefore, with the above notation in mind, on any particular day, D, a grower will experience, in general, costs associated with protection, $CST_{I,J,K,M,D}$, and losses, $LOS_{I,J,K,M,D}$, resulting from

inadequate or lack of protection when frost occurs. Therefore, the event costs and losses, averaged over a frost season are

$$COST_{I,J,K,M} = \frac{1}{N_{I,J,K,M}} \sum_{D=1}^{MAXD} CST_{I,J,K,M,D}$$

$$LOSS_{I,J,K,M} = \frac{1}{N_{I,J,K,M}} \sum_{D=1}^{MAXD} LOS_{I,J,K,M,D}$$

$$EXP_{I,J,K,M} = COST_{I,J,K,M} + LOSS_{I,J,K,M}$$

where $N_{I,J,K,M}$ is the number of days, during the time period consisting of MAXD days, that the event or situation I occurred with "magnitude" characterized by M to the K^{th} grove of type J. Note that events associated with I = 4, 8, 11 and 15 are not to be considered in the cost and loss computations. The reason for this is that these events are the result of constraints upon the grower choices of action which have little or nothing to do with the weather forecasts, actual weather and grower believability of the forecasts. Care must be taken to eliminate an appropriate number of days, as will be seen in following paragraphs, when extrapolating the results of the samples obtained during the course of the experiment.

Let unprimed quantities denote test group data and primed quantities denote control group data.

The cost and loss per acre per day associated with the I^{th} event is

$$EXPA_{I,J,K,M} = EXP_{I,J,K,M}/ACRE_{J,K}$$

where $ACRE_{J,K}$ is the number of citrus acres associated with the K^{th} grove of the J^{th} type. The average cost and loss per acre per day of

the event, $\overline{EXPA}_{I,J,M}$, is obtained from

$$\overline{EXPA}_{I,J,M} = \frac{1}{MAXK} \sum_{K=1}^{MAXK} EXPA_{I,J,K,M}$$

In a similar manner, the average number of days per J type is

$$\overline{N}_{I,J,M} = \frac{1}{MAXK} \sum_{K=1}^{MAXK} N_{I,J,K,M}$$

The average number of actual frost days, $\overline{NFD}_{J,M}$, of intensity M is obtained as follows:

$$NFD_{J,K,M} = \sum_{I=5}^{7} N_{I,J,K,M} + \sum_{I=13}^{16} N_{I,J,K,M} - N_{15,J,K,M}$$

and

$$\overline{NFD}_{J,M} = \frac{1}{MAXK} \sum_{K=1}^{MAXK} NFD_{J,K,M}$$

As mentioned previously, the M subscript is a measure of the severity of the frost measured in degree-hours of frost (relative to 28°F). The severity of the frost (in terms of the degree-hour measure) can not normally be measured in the grove which has undergone protective action since the protective action, as is its purpose, perturbs the temperature which would have occurred if protective action had not been taken. Therefore, it is necessary to obtain temperature measurements on control thermometers of the NWS or other nearby locations where temperatures are not perturbed by the protective actions of growers. It is thus necessary to develop a functional relationship between control thermometer temperature and the temperature which would have occurred in the grove if protective action were not taken. It is this latter temperature which is utilized (together with duration) as a measure of grove frost severity.

Since statistics are available of number of frost days per year, it is desirable to reference all costs and losses to this quantity and use frost days per year, NO_J, as a basic scaling factor. The average cost and loss per frost season experienced by the citrus growers, $\overline{EX}$, is therefore*

$$\overline{EX} = \frac{ACRET}{10000.} * \sum_{I=1}^{16} \sum_{J=1}^{MAXJ} \left\{ NO_J * PACRE_J * \sum_{M=1}^{MAXM} PNO_{J,M} * \overline{EXPA}_{I,J,M} * \overline{N}_{I,J,M}/\overline{NFD}_{J,M} \right\}$$

where ACRET is the total number of acres devoted to citrus crops, $PACRE_J$ is the percentage (%) of the total acres which are classified as type J, and $PNO_{J,M}$ is the percentage (%) of the number of frost days in areas of type J which are of severity M.

$\overline{EX}$ represents the total costs and losses as obtained from the <u>test group</u> data samples extrapolated to the total citrus crop acreage and specified number of frost days per frost season. Similarly, $\overline{EX}'$ can be established representing the total cost and losses as obtained from the control group data samples and similarly extrapolated. The average annual incremental benefits, $\overline{AB}$, to citrus growers, as measured by the difference in the annual cost of frost protection and losses due to frost, are obtained as the difference in annual cost and

*This is an approximation which is useful, because of its simplicity, when $NO_J * PNO_{J,M}$ is not too different from $\overline{NFD}_{J,M}$. If this approximation is not valid, then the methodology developed in Appendix B must be employed. The reason that this is an approximation is that in reality, with a specified frost season duration, the ratios of $\overline{N}_{I,J,M}/\overline{NFD}_{J,M}$, across all I, do not remain constant with variations in the number of frost days. This is somewhat analogous to sampling from a small population without replacement.

losses, $\overline{EX}'$ which results from scaling of the control group data samples and the annual cost and losses, $\overline{EX}$, which result from scaling of the test group data samples. Therefore, the annual incremental benefits are

$$\overline{AB} = \overline{EX}' - \overline{EX}$$

The methodology for establishing the values of costs and losses is described in the following section.

4.3.3 Cost Determination

The purpose of this section is to outline the method by which the nightly cost of frost protection could be computed for an individual grower. There are three major components of total cost which are incurred by the grower. The first two, the variable costs, are (1) the nightly labor cost including the wages of the laborers, foremen, and the grower, and (2) the nightly wind machine and heater fuel costs. The third component is the depreciation on capital equipment, i.e., wind machines and the flame throwing trucks, which is a fixed cost.* It is anticipated that this will not be considered in the ASVT experiment.

Practical measurement of the nightly total frost protection cost can be made easier if the determinants of the labor and fuel, costs, such as the wage rates, fuel consumption rates, hours of wind

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*This may also be considered as a variable annual cost when depreciation is directly related useage. This implies fixed cost per use but variable cost per year since the number of uses per year is a variable. If it is found the this is a necessary and important distinction, then the variable depreciation cost considerations will be included in the determination of total annual cost.

machine operation, etc., are separated into those which can be observed nightly and those which remain fairly constant over the frost season. Such a classification or method of computation will improve the efficiency of the experiment data collection process since roughly half of the cost determinants would be collected only once, at the beginning of the frost season. Table 4.16 lists the cost determinants which are necessary to compute the nightly cost of frost protection. The four equations immediately below, which use the notation found in Table 4.16, illustrate a direct method of computation.

(1) Wind Machine Fuel Cost = e*b*ℓ*k

(2) Heater Fuel Cost = j*g*n*q

(3) Wind Machine Labor Cost =(m*o*c)+(n*p*d)

(4) Heater Labor Cost =(s*u*h)+(t*v*i)

The sum of the fuel and labor costs is equal to the total nightly costs of frost protection. Though the derivation of these equations was straight forward, there are a number of possible problem areas which remain to be examined. The first deals with the assumption that the price of heater and wind machine fuel remains constant over the frost season. During a recent field trip to Florida, it was discovered that many growers do indeed pay a constant price for their fuel regardless of fuel market price fluctuations. This is because the growers either buy their fuel once a season and store the fuel in storage tanks or they sign a contract to purchase a given number of gallons during the season at a fixed contract price. It is possible though that some growers buy at the current market price through the season alternatively enjoying or suffering the effects of the price

Table 4.16 The Variables to Be Used in the Computation of Frost Protection Cost

Variables	Symbol
Seasonal Constants:	
Wind Machine Related Costs:	
1. total number of wind machines	a
2. fuel consumption per machine (gallons/hour)	b
3. hourly wage for wind machine operators ($/hour)	c
4. hourly wage for wind machine foremen ($/hour)	d
5. price of wind machine fuel ($/gallon)	e
Heater Related Costs:	
1. total number of heaters	f
2. fuel consumption per heater (gallons/hour)	g
3. hourly wage for heater operators ($/hour)	h
4. hourly wage for heater foremen ($/hour)	i
5. price of heater fuel ($/gallon)	j
Nightly Variables:	
Wind Machine Related Costs:	
1. number of wind machines used during night	k
2. number of hours and tenths of hours each machine in operation during night	l
3. number of machine operators hired for night	m
4. number of foremen used	n
5. number of hours worked by each operator	o
6. number of hours worked by each foreman	p
Heater Related Costs:	
1. number of heaters used during night	q
2. number of hours and tenths of hours each heater in operation during night	r
3. number of heater operators hired for night	s
4. number of heater foremen used	t
5. number of hours worked by operators	u
6. number of hours worked by foremen	v

movements. If one of these growers is chosen to participate in the experiment, the suitable corrections will have to be made. Another potential problem area could result if a participating grower suffers a damaging freeze. If there has been significant tree damage and/or fruit loss, the grower will radically change his frost protection strategy. For example if the grower has been forced to salvage his freeze-damaged fruit by picking immediately after the freeze, he will not protect his groves at the temperatures he would have previously. He will only protect at the lower temperatures (mid 20's) to save his trees. Since the occurrence of a damaging freeze might perturb the experiment results, care must be taken to adjust the measured data for the effects of the damaging freezes. This problem may be avoided to a certain extent if the cost determination process simulates the frost protection strategy the grower would have used if the damaging freeze had not occurred. Assuming that enough nights had been observed prior to the freeze, the same level of frost protection would be simulated given the actual nightly temperature ranges.

In conclusion, it is possible that the actual method of cost calculation may differ from that outlined in equations 1 through 4 when more is learned about each grower's daily operation during the course of the experiment. Equations 1 through 4 and Table 4.16 only serve to point out the type of data that need to be collected.

4.3.4 Loss Determination

This section is concerned with the method of computing the losses incurred by an individual grower as a result of a missed or inaccurate forecast. The notion of economic loss is quite different from

the notion of economic cost. The most important distinction between the two is that an economic loss is not recoverable while an economic cost is reflected in the product's price and is therefore recoverable to the producer. There are two major components of loss to be evaluated for the ASVT experiment. The first is the freeze related fruit losses which are subdivided into partial losses in the case of mature fruit and total losses in the case of immature fruit. Freeze damaged mature fruit can be picked immediately after the freeze and sold at a lower fresh fruit grade or as concentrate. Damaged immature fruit is usually not salvageable. The second loss area involves the reductions in production and higher nuturing costs resulting from freeze related citrus tree damages.

As was the case in the previous section on cost determination the practical measurement of freeze related losses is made easier if the determinants of these losses are divided into those which can be observed once a frost season and those which will be observed given a freeze occurance. Table 4.17 lists the loss determinants which appear to be necessary to establish quantitative values of loss. Using the notation of Table 4.17, the computational equations are;

(1) Partial Fruit Loss (mature fruit)=F*(G-H)

(2) Total Fruit Loss (immature fruit) =(I*J)-(I*A)

(3) Yearly Tree Loss = (L*B*C) + (L*E) - (L*B*A)

(4) $$\text{Present Value of Total Tree Loss over Period} = \sum_{i=o}^{K} (1/(1+D)^{i})*\text{Yearly Tree Loss}$$

There are a number of explanatory points and possible problem areas which should be discussed in reference to the above four equations. First, the nuturing costs and production levels per tree will

Table 4.17: The Variables to be Used in the Computation of Freeze Related Losses

	Symbols:
Seasonal Constants:	
Fruit Related Losses;	
1. harvesting and primary transportation costs ($/bushel)	A
Tree Related Losses:	
1. normal yearly production per tree per year by age group, variety (bushels)	B
2. expected price by variety ($/bushel/year)	C
3. citrus industry rate of discount (decimal)	D
4. nuturing costs per year per tree if damaged, including costs of increased frost protection ($/tree/year)	E
Occurance Variables:	
Fruit Related Losses (Partial)	
1. number of mature fruit bushels damaged by variety (bushels)	F
2. price fruit could have sold for at expected grade ($/bushel)	G
3. price fruit did sell for at lower grade ($/bushel)	H
Fruit Related Losses (Total)	
1. number of immature fruit bushels lost by variety (bushels)	I
2. price fruit could have sold for at expected grade ($/bushel)	J
Tree Related Losses	
1. number of years before return to full production (years)	K
2. number of trees damaged by by freeze	L
3. age structure of trees (years)	M

remain constant only over the season and will be allowed to vary year to year so that the gradual return to health of a damaged tree can be simulated more accurately. Secondly, if a grove of trees is completely killed by a freeze, the variable K, or the number of years before return to full production will be assigned one of two values. If the grower plans to replant the dead grove with nursery trees, K will take on the value of 12, the number of years needed for a new grove to reach maturity. If the grower decides not to replant, K will be (75-M), a conservative estimate of a citrus tree's productive life span where M is the present age of the tree. Thirdly, though the computational scheme outlined could have used the "on tree" fruit prices, and thereby circumvent the need for transportation and harvesting cost data, free on board (FOB) prices will be used since they are more representative of the market, published more frequently, and are readily available.

Finally, there exists the problem of estimating the yearly "expected" price per bushel and nurturing costs in the future. Since a damaged tree may not return to full production for 5-7 years, and since it is anticipated that the ASVT will allow only 2-3 years of actual data collection, it will be necessary to forecast future citrus prices and nurturing costs. The expected nurturing costs are especially difficult to assess since these nurturing costs include the increased costs of frost protection for the weakened trees. To perfectly estimate the future frost protection cost, severity of each frost season would also have to be perfectly forecast. For lack of any better method, the expected value of the future fruit prices and nurturing costs will

be estimated by taking an average price for a given number of years. The effects of inflation on these prices could be solved by choosing a discount rate which includes the effects of the expected inflation rate.

4.3.5 Control Group Possibilities

In the previous section on experiment methodology, a technique of benefit measurement accomplished by comparison of control and test group results was outlined. Furthermore, it was pointed out that as opposed to most experiments where the control and test groups are physically separated, the above methodology called for temporal separation of the groups. The temporal solution was arrived at for the Florida experiment since it would be unjust and impractical to isolate a control group within Florida which would not benefit from the SMS improved frost warnings. It is the purpose of this section to evaluate the strengths and weaknesses of two alternative methods of control group and test group temporal separation. The first method would rely on historical meteorological and economic records to reconstruct a control group cost of protection and freeze related losses. The second method would use the economic data on grower costs and losses collected during the 1976-77 frost season as the control group. According to current plans the SMS improved frost forecasts will not begin until the 1977-78 season and consequently the collection of test group economic data would begin then.

In evaluating the relative merits of using a historical control group vs. the 1976-77 frost season control group, four criteria are considered, namely: (1) the availability and quality

of economic data at the individual grower's level, (2) the availability and quality of temperature and duration data at both the grower's level and for the various NWS forecast zones, (3) the possibility of selecting a statistically significant sample, and (4) the possibility of normalizing the important effects of frost frequency, changes in forecasts skill, etc., between the test and candidate control groups.

4.3.5.1 Historical Control Group

As pointed out in section 4.2.7, historical records of the important aggregate economic and meteorological variables are quite complete. The National Weather Service has kept temperature and duration records for some 200 government thermometers throughout the state since the mid 1930's. In addition, the NWS forecasted temperatures and durations for each forecast zone in Florida are available for at least ten years. As to the aggregate economic data, Florida Citrus Mutual, the Growers Administrative Committee, and the Economic Research Department at the University of Florida have kept extensive production and price records for several years.

Unfortunately, there are almost no nightly data kept by individual growers. Only one grower was found to keep detailed historical records on nightly frost protection decisions, and the total protected acreage of this co-operative association was only .5 percent of the total protected acreage in Florida. This same grower did not experience any significant freeze related losses for the period of record. The Haines City records by themselves, see Table 4.12, told only of the frost protection actions taken, the temperature at which the action was taken, and the duration of each action. In order

to compute the nightly cost of protection, other data would be needed. Given that the heaters were run for five hours in a particular grove, data such as the price per gallon of fuel used per hour of operation, the number of operators used per hour of operation, and the number of heaters in the grove, all would be needed. Though it might be possible to find fuel price records and assume a constant number of heaters or wind machines per grove over the historical period, the lack of manpower records would make accurate calculation of nightly costs difficult.

Another problem area that would arise in using a historical control group would be the need to account for the effects of changes in forecast skill and fuel price movements on the grower's frost protection decisions. As pointed out in the earlier section on experiment methodology (section 4.3.2), it is very important to account for the effects of non-SMS related variables on the grower's decision processes, so that the cost and loss comparisons between the test and control groups measure the true savings of the SMS improved forecast. For example, though the change in historical forecasting skill might be small enough to ignore over a three year period, the rapid use in fuel prices over the past 2-3 years has definitely changed many growers frost prediction strategy. This point was raised several times by the growers who were interviewed during the Florida field trips.

In conclusion, the use of a historical control group would present several severe problems for the experiment. Reexamining the criteria introduced at the beginning of the section, it is evident that each of the four criteria were not met. There are vitually no economic or meteorological historical records kept by growers, the

records of one co-operative would not constitute a statistically valid sample, and finally, the effects of increases in fuel prices would be extremely difficult to account for.

4.3.5.2 1976-1977 Frost Season

If the SMS-improved frost forecasts do not begin until late 1977, the 1976-1977 frost season could be used to collect the cost of frost protection and freeze related loss data from a control group of growers. Such an undertaking would require the selection of a statistically significant sample of growers who would be willing to participate. The nightly information needed from each control group would include hourly labor and fuel use as outlined in Section 4.3.3 on cost determination. If the grower experienced a damaging freeze, fruit price and extent of fruit and tree damage data would be collected as pointed out in Section 4.3.4 on loss determination. Additionally, detailed temperature and duration records would be needed from the grower for each of his protected groves. National Weather Service forecasts and actual temperature readings from the 200 temperature stations would also have to be collected.

There are several advantages in using the 1976-1977 frost season as the period for control group measurement. First, and most importantly, the size and the nature of the control group sample can be controlled. In choosing the sample, growers can be selected by the type of citrus grown, soil type, relative elevation, and frequency of frost occurance so that the sample will be representative of all growers. Secondly, since the period of measurement for the control group will

immediately precede the period of test group measurement, the perturbing effects of many industry economic variables will be minimized. For example, the effects of the huge fuel price increases that occurred during the 1973-1974 season have now probably bottomed out. Those growers who found it economically infeasible to use fuel dependent frost protection methods, have already made the switch to other methods or have stopped protecting altogether. Alternatively, those growers who have become cautious in their use of fuel due to the high prices have already mastered the techniques of fuel conservation.

On the other hand, there are two major problems which would arise if the 1976-1977 frost season control group were used. Though most growers have at least one thermometer in each grove and do take frequent readings during the night, the recorded temperatures will be perturbed by the use of frost protection devices, and they will not represent the "true" air temperature. This creates a difficult problem for the experiment methodology. As discussed in Section 4.3.2 on methodology, the comparison between the test and control groups' nightly cost of protection will be accomplished by comparing costs on nights which have similar temperature patterns. This important step is necessary so that the ASVT experiment will measure the true reductions in the costs of frost protection and not the effects of varying levels of frost intensity. This problem was discussed at length with Mr. Jim Georg of the Federal-State Agricultural Service in Lakeland. Mr. Georg suggested that full use be made of the 200 NWS thermometers throughout the state to extrapolate the true temperature in a given grove. In order to do this, correlation coefficients would have to be derived for each of the groves included in the test and control groups. Fortunately,

some work has already been done in this area, as Dr. Jon Bartholic's team at the University of Florida is using the same 200 thermometers in conjunction with the SMS temperature maps in developing their frost forecasting models. In addition, Mr. Jim Georg has used these thermometers for the past 20 years to make informal grove forecasts over the phone for interested growers (see Section 4.2.4, Current Forecasting Capability).

The other problem with the 1976-1977 control group is the fact that it will represent only one season of data and as a result it is unlikely that the effects of the whole spectrum of various frost and freeze events that can affect Florida would be measured. This problem, of course, cannot be solved.

In conclusion, though the use of 1976-1977 frost season as the period of control group measurement presents problems, it satisfies more of the above criteria than the use of the historical control group. The size of the control group can be made large enough to be statistically significant, and the type of grower included in the sample can be chosen on the basis of representativeness.

4.3.6 Test Group

Measurement of test group costs and losses would follow much the same pattern as outlined in the above section on control group measurement. A representative sample of sufficient size would be chosen to record nightly fuel and manpower use. Collection of the nightly data would probably be most easily accomplished by a questionnaire which lists the needed data. Each grower could be given a pad of these questionnaires so that he could have a fresh copy for each frost night. The questionnaires would then be collected, in person,

once every two weeks or mailed to a central Florida address. It might also be possible to have two levels of participation open to each grower at the beginning of the experiment. One group of growers would commit themselves to keep the nightly records as outlined above. The other group would be called upon to keep records on only 3 to 4 nights a frost season, in order to give the experiment more information on crucial or severe frost nights. At the beginning of the frost season, the seasonal constants such as number of wind machines, fuel consumption rates per hour of operation would be collected. The SMS improved forecasts and actual NWS recorded temperatures would also be needed.

As was the case with the use of the 1976-1977 control group, individual grove temperature readings would be suspect due to the presence of heating equipment. This problem would have to be corrected by the derivation of temperature correlation coefficients for each grove in the test group. There is another problem which is unique to the test group. Since measurement of the test group costs and losses will begin at the same time that the SMS improved frost forecasting begins, there may be a learning period experienced by the NWS personnel until they become familiar with the new techniques.

As a result, the quality of the forecasts will gradually improve up to some constant level of forecast skill which is the maximum attainable under the new forecast system. This period of gradual improvement may be on the order of months or even longer, and consequently the first year of test group measurement might produce results which reflect this learning process but not the maximum attainable level of

grower cost and loss reduction. This problem can be alleviated if the test group costs and losses are measured for more than one frost season.

4.3.7 Sampling Possibilities

4.3.7.1 Sample Frame

The main citrus producing area in Florida is located in the central region of the state around the sandy ridge extending north-south within the interior of the peninsula. It is in this region where the citrus production is significantly influenced by the weather conditions and therefore the protection of the citrus crop and citrus trees plays an important role. But even in this region not all of the citrus groves are protected against the effect of the freezing temperature. It has been estimated [7] that in two counties, Lake and Orange, which have 24.4 percent (192,700 acres) of the state's total 791,000 citrus bearing acres, only 15.1 percent (29,100) of that is protected. From this, less than one-half is protected by the heaters (7.2% of total Lake-Orange acreage) and slightly more than one-half is protected by the wind machines (7.9% of total Lake-Orange acreage). Furthermore, the protected acreage of these two counties accounts approximately for one-third of the protected acreage in the whole state [7].

The distribution of the protected acreage throughout the citrus region is very important in determining the target population, the survey population, and finally, the sampling frame. The target population is considered to be the total citrus producing acreage which is protected against the possibility of freezing temperatures. However, the protection of citrus is less important in southern areas of peninsular Florida and only acreage allocated for the specific fruit and

nurseries is protected. Also, the citrus-bearing acreage in the northern areas of the peninsula, even if they are almost all protected, represent only a small fraction of the total protected acreage. Therefore, it seems reasonable to exclude the citrus-bearing protected acreage in the southern and northern areas of the peninsula from the data gathering portion of the experiment. The survey population is therefore defined as the citrus-bearing acreage which is protected against the possibility of freezing temperatures and is geographically located in the central region of the peninsula Florida. It is this population from which cooperative growers will be selected for partici-pation in the control and test groups. The survey population is es-timated as comprising approximately 95 percent of the target population.

In order to estimate both the number of growers included in the target population and the number of growers who might participate in the ASVT experiment, ECON contacted two USDA multicounty extension agents. These extension agents* assist citrus growers in the prime protected producing areas of Polk, Lake, Orange and other East Coast counties. Table 4.18 lists their estimates of total acreage and growers, protected acreage and growers, and importantly, an estimate of the number of growers who might participate and the acreage involved. The 51,000 protected acres within their district represents approxi-mately 64 percent of the total protected acreage in Florida. Both agents cautioned that these estimates would have to be revised when the new Florida Livestock and Crop Reporting Service statistics are released in September 1976.

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*Dr. John Jackson and Dr. Tom Oswalt.

Table 4.18 Estimate of Grower Survey Population and Sample Size Based on Data from the Major Frost-Affected Citrus Producing Areas*

	Total Acreage	Growers	Groves**
Total	326,000	7,200	8,000-9,000
Frost Protected	51,000	230	1,200-1,300
Frost Protected and Probable Participants	20,000	55	400- 600

*Based on Lake, Orange and Polk Counties and parts of other counties on East Coast.

**Assumes average grove size of 40 acres.

The survey population may be divided for sampling purposes into sampling units. For the case at hand, the sampling unit is the citrus-producing grove which is protected against the effects of frost and/or freeze. A grove containing a minimum of 50 citrus-bearing trees is considered to be the smallest unit. This is consistent with the Florida Department of Agriculture's Commercial Citrus Inventory [12] published biennially. Groves vary in size, the large groves may contain several thousand acres of trees and the effect of the size will be included in an evaluation of the sampling.

There are two basic types of sampling frames, namely the area frame sampling and the list frame sampling. These sampling frames, and their combination, the multi-frame sampling, are currently used in the collection of data for agricultural statistics [14].

In area frame sampling, the frame consists of an aggregation of characteristics concerned with agriculture associated with these

sample segments using three different concepts: the closed segment, the open segment, and the weighted segment [14]. The closed segment includes all agriculture that is inside the segment boundaries and excludes all that is not. In the open segment all activities of farms with headquarters located inside the segment are associated with the segment even if some activities are outside the segment boundaries. In the weighted segment, all agriculture associated with a farm is attributed to the segment in proportion to the fraction of the farm acreage that is inside the segment.

A list frame is a list of identified elements from the sampled population. For the particular case under consideration, lists of names and addresses of growers and grove managers will be used in collection of information. The cost of data collection from the list frame is relatively low. The indexing of various characteristics used for efficient stratified sample designs can be easily developed and incorporated in the list frame. The list frame, however, is almost never "complete" because the units of the frame, i.e., groves, are continually changing. Therefore, only non-probability sampling is used with a list frame.

This disadvantage is removed in multiple-frame sampling where more than one frame is used. For agricultural statistical purposes this implies the use of both a list frame and an area frame. This method is very effective for specialized types of crops, such as citrus, which are not correlated with land alone. For the citrus experiment, some of the main characteristics pertinent to the sampling, such

as frost protection technology, variety of citrus, use of crop, micro-meteorological factors and the cost associated with the frost/freeze protection, are not associated with land. Therefore, most of the data for population can be collected more efficiently through the list frame. The area frame complements the list frame and thus allows the applications of probability surveys.

A variety of list sources are available for the development of the list frame to be used in the ASVT experiment. The following organizations and associated statistical records are available for use:

a. Florida Department of Agriculture and Consumer Services,
b. Florida Crop and Livestock Reporting Service,
c. Agricultural Stabilization and Conservation Service,
d. State Farm Census,
e. Assessor's records,
f. State Government records maintained for inspection and controls,
g. records of Florida Cooperative Extension Service, University of Florida, Institute of Food and Agricultural Science, and
h. citrus growers' records.

One of the most important records for the construction of the list frame would be those of Florida Cooperative Extension Service, which are periodically updated by the County Extension Agents. They have an intimate knowledge of almost all citrus groves in their districts (one or more counties) and maintain a constant communication with citrus growers. Their help would be especially valuable in

determining the size and character of frost protection technology used on particular groves (the sampling units), temperature characteristics, decision policies, etc.

4.3.7.2 Important Factors to Include in Sampling Plan - Stratification

There are a number of factors which play an important role in a successful sampling. These factors and their influence can be identified during the construction of the list frame. This prior knowledge about the population is necessary in the development of a stratified sample. The population is divided into homogenous subsets--strata--and then only a relatively small number of observations is needed to determine the characteristics of each subset. This would be advantageous compared to the simple random sampling which requires an access to all items in the population at increased cost and is difficult to implement.

The stratification within the sample frame can be based at least on the following variables:

1. Geographical location. Groves located in the northern part of the Florida citrus belt naturally need more frost protection than those located in the south. Geographical stratification thus separates different citrus-producing districts.
2. Micrometeorology. Local topography, altitude, presence of large bodies of water, soil type, etc.
3. Variety of citrus. Certain varieties are more sensitive to freezing temperatures and require greater protection (Table 4.8). The maturity of fruit is another important

consideration linked to the citrus variety. Early oranges are picked before or at the beginning of the winter season. Midseason varieties mature during the winter months and if damaged due to frost and/or freeze, they can be harvested almost immediately and the potential losses could be thus minimized. The late varieties, harvested during the spring, require more protection and, if damaged, the losses are more severe. Finally, the specialty fruits are more protected against the freezing temperature effects, because of the higher market values they command. The stratification according to the variety will account for the factors described above.

4. Size of a grove. The trees in large groves tend to reduce the velocity of cold winds during advective freezes and mixing of cold air components is better in larger groves. The unit costs (per acre of grove) associated with the labor cost, transportation of fuel, cost of fuel and the capital cost of the protection technology are smaller for the larger groves.

5. Age of trees. Citrus trees become less susceptible to injuries caused by freezing temperatures as they get older [13]. The statistical records of Florida Crop and Livestock Reporting Service list all citrus trees by their age.

6. Frost protection technology. The stratification of the sample population according to the use of the frost protection technology is essential. The capital expenditure, and the cost of fuel and labor are substantially different when the heaters and wind machines are used separately or or in a combination.
7. Use of the crop--fresh or processed. This variable takes into account the differences in prices of fresh or processed fruit which are very high for some special varieties.
8. Cooperation of growers and grove managers. This variable is very important in the effort to obtain as complete a list of all measured characteristics as possible. The complete and timely return of questionnaires and cooperation during interviews are necessary for the successful collection of data. The previous experience of USDA and University of Florida officials will be used to stratify the sampling frame using this variable.

These seem to be the major variables influencing the protection measures. There are other variables, such as risk adversity of growers, price of fuel, concentrate future prices, etc., which are not measured directly but have an impact on all measured variables and also on the cold protection strategy.

4.4 Experiment Plan

The following paragraphs describe a plan for accomplishing the demonstration of the economic benefits which are expected to result from improved temperature and frost forecasts made possible by

timely temperature data obtained from the Synchronous Meteorological Satellite (SMS). The plan describes the specific tasks which must be carried out as part of the experiment including detailed experiment design (which encompasses the determination of the sampling plan, design of forms for data collection, cost determination methodology, loss determination methodology, extrapolation methods, etc.), data collection and training, data analysis, etc. A specific task on econometric modeling to evaluate the potential economic benefits of improved temperature knowledge on marketing decisions is also delineated. The plan also develops a schedule for the performance of the demonstration of the economic benefits, and presents manpower requirements and budget estimates. Finally, the plan considers the various participants (government agencies, universities and industry), their roles and the coordination of their various activities.

4.4.1 Description of Experiment

The experiment is concerned with demonstrating the economic benefits which are expected to result from improved temperature and frost forecasts made possible by timely temperature data obtained from the SMS. It is anticipated that the citrus growers will use the improved temperature forecasts to improve decisions pertaining to frost protection and will result in reduced protection costs and reduced crop losses. The experiment considered in this plan is aimed at measuring the change in annual protection costs and crop losses which are the direct result of improved temperature forecasts.

SMS temperature data can also play a role in frost damage assessment by providing a current comprehensive record of actual temperatures. SMS data may also play an important role in harvesting

and pricing decisions (i.e., marketing decisions) whereby growers have more information on the status of other citrus growers' crops as impacted by temperature conditions. Because of the limited number of frost seasons which can realistically be considered, the experiment considered in this plan is <u>not</u> aimed at measuring the benefits from the improved harvesting and pricing decisions.

The experiment requires the formation of a control group and a test group for establishing the protection costs and crop losses without and with the improved temperature forecasts, respectively. The control group will rely primarily upon a cooperative group of citrus growers who will provide temperature, decision, action, cost and loss related data during the 1976-77 frost season. It is assumed that the SMS temperature data will not be available for operational use prior to the 1977-78 frost season. The control group will also incorporate appropriate historical data from the few citrus growers that have maintained detailed records. The test group will consist of basically the same set of citrus growers who make up the control group, but the test group will provide data during the 1977-78 and following frost seasons. It does not seem appropriate to place total reliance on the 1977-78 frost season data since this will be the first exposure of the test group to the improved temperature forecasts and, as such, may not be truly indicative of the longer term steady-state operations. Thus the test group should, as a minimum, also consider the 1978-79 frost season.

The specific number of growers and groves and their geographic distribution has not as yet been determined. This, the sampling plan, is one of the immediate tasks which is to be undertaken as part of the

detailed experiment design (see Section 4.4.2.1). The objective of the sample plan is to select a large enough representative sample of growers who will provide data for the experiment such that costs and losses can be established for the control and test groups. The sample must be of sufficient size and segmentation so that the differences in costs and losses can be credibly established. The USDA County Extension Agent's experience with the growers will play a major role in the design of the sampling plan.

In order to establish the costs and losses associated with each grove, which are then aggregated and averaged to establish average cost and loss per frost day (see Section 4.3.2), it is necessary to segment the data collection according to event type (i.e., the combination of actual weather, forecast, grower belief of forecast and action taken), grove type (i.e., the combination of the general conditions within the grove such as soil type, elevation, nearness to large bodies of water, etc., and the general grove practices such as use of heaters, sprinklers, risk attitudes, etc.), and frost severity in terms of a degree-hour measure.

The data to be provided by the citrus growers consists of both seasonal and daily data. The seasonal data consists of information which may be considered, for purposes of the experiment, to remain constant during the frost season and consists of

- Average wage rate ($/hour),
- Heater fuel consumption (gallons/hour/heater/grove),
- Wind Machine fuel consumption (gallons/hour/blower/grove),
- Average citrus crop yield (bushels/grove),

- Citrus crop type per grove,
- Grove size (acres) ,
- Grove location (including general terrain features),
- Grove elevation (feet),
- Grove soil type,
- Number of heaters per grove ,
- Number of wind machines blowers per grove, and
- Etc.

The grove daily data must be collected for each night during the frost season except* on those nights where clearly there is no possible chance of frost occurring. The data consist of

- Crews alerted? (yes or no/grove),
- Number of men employed in grove (men/hour/grove),
- Number of heaters used (heaters/hour/grove),
- Number of wind machines used (wind machines/hour/grove),
- Grove temperature (°F/hour/grove),
- Control thermometer temperature (°F/hour/grove),
- Forecast temperature (°F/hour/grove),
- Tree damage (percentage of yield/grove),
- Tree damage recovery rate (estimated percent reduction in following growing season/grove),
- Crop loss (number of bushels picked for concentrate because of frost on day X/grove),
- Etc.

In order to establish the protection costs and crop losses, other general data is necessary and need not be provided by the growers.

*The exception is an attempt to minimize the grower data collection task.

This data consists of citrus (by type) futures and spot prices, concentrate (by type) spot prices, fuel prices, etc.

Finally, data must be provided by the National Weather Service. This data would consist of weather forecasts and actual temperature measurements at the NWS control thermometers. The control thermometer measurements will be used to establish a measure of the grove temperature which would have been experienced if protective measures had not been undertaken*. In essence, the control thermometer measurements, suitably modified to account for grove location relative to the control thermometer, are used to establish the frost severity measure (degree-hours)--i.e., the severity of the frost which would have occurred if there was no protection.

The collected data must constantly be reviewed and coordination maintained with the citrus growers and the National Weather Service. The collected data will allow cost and loss per event to be established for both the control and test groups and then the annual costs and losses for both groups for a specified average number of frost days per year. This then will result in the determination of the annual benefits (both economic and fuel conservation) which were demonstrated to result from the improved temperature forecasting. These benefits, based upon the sample set, can then be extrapolated to the total Florida citrus industry, taking into account the geographic distribution of groves, temperature patterns and frost protection practices of the growers.

*This is only necessary if there is not a control thermometer specifically established for the grove.

A detailed functional flow of the economic experiment portion of the Florida citrus crop ASVT is presented in Figure 4.16. The specific tasks are discussed in further detail in Section 4.4.2 and the schedule of events (i.e., the time dimension associated with Figure 4.16) is presented in Section 4.4.3. The participants, their respective roles and coordination are discussed in Section 4.4.4. Finally, manpower requirements and budgetary estimates are presented in Section 4.4.5 and 4.4.6, respectively.

4.4.2 Tasks

The economic experiment requires the successful completion of many detailed and diverse efforts. These have been grouped into five major tasks which are described below, namely (1) Detailed Experiment Design, (2) Data Collection, (3) Data Reduction, (4) Economic Analysis, and (5) Reporting. A sixth task, entitled Econometric Modeling, is also discussed, though not an integral part of a demonstration experiment (since the benefits with which it is concerned cannot be demonstrated credibly within the practical time frame of the experiment). This latter task is necessary to assess the economic benefits which may result from improved temperature knowledge which may impact marketing decisions.

4.4.2.1 Detailed Experiment Design

This task is concerned with the development of the sampling plan, the methodology for establishing protection costs and losses resulting from inadequate protection in terms of temperature forecasting capability, and the development of the means for collecting data which will demonstrate the economic (and fuel conservation) consequences of improved temperature forecasting.

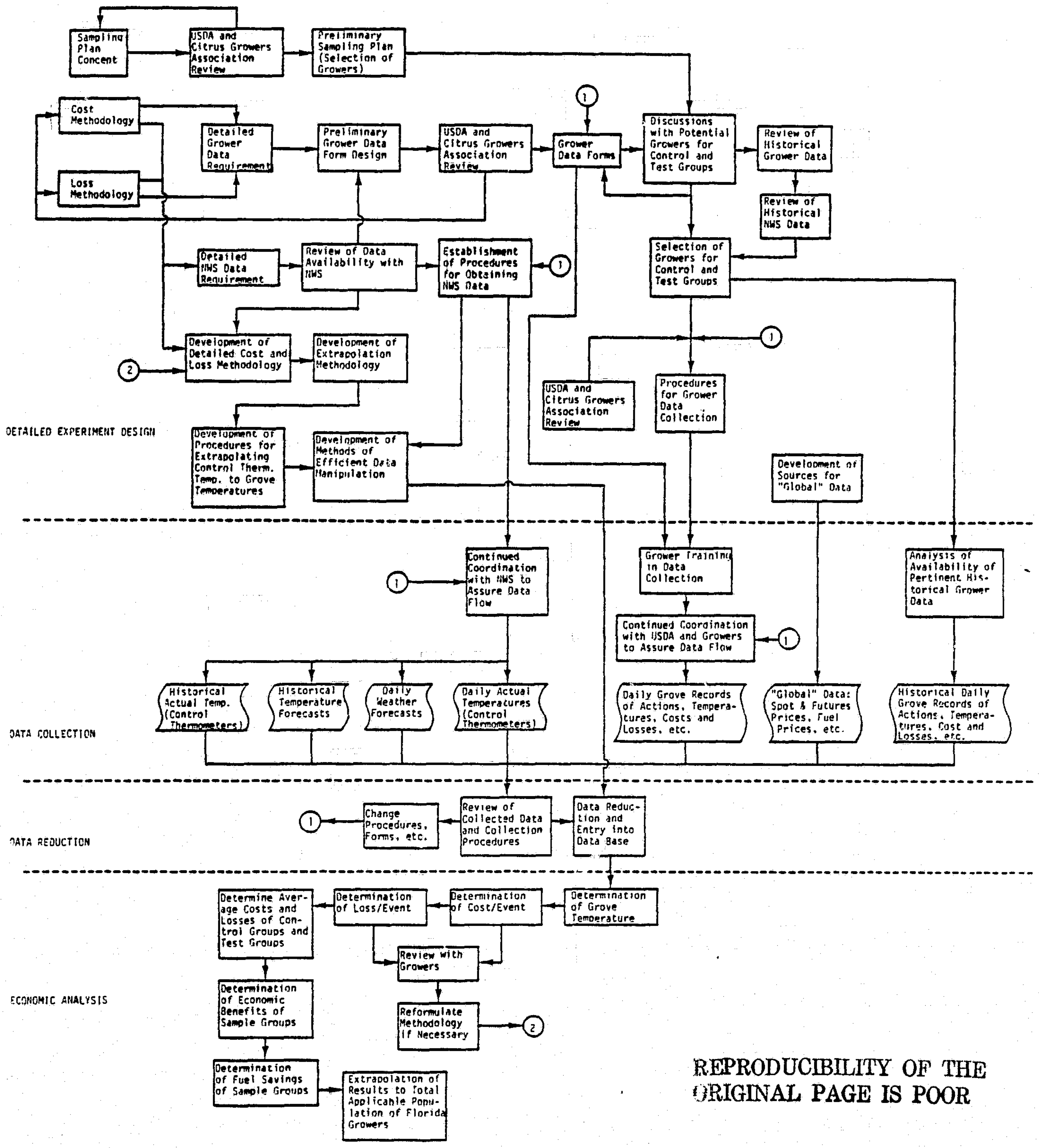

Figure 4.16 Functional Flow of Florida Citrus Crop ASVT (Economic Experiment)

The sampling plan is concerned with the determination of the specific growers (and groves) who will participate in the conduct of the experiment. The specific grower selection process must consider the desired number of samples to be included in the test and control groups. This will include consideration of the accuracy of the data and the segmentation requirements (in terms of geographic location, frost protection practices, soil type, citrus crop type, etc.). A major consideration must be USDA experience with growers and the population of growers which are expected to be cooperative. It is envisioned that a sampling plan concept would be developed and thence reviewed with the USDA and Citrus Growers Association, the result being a preliminary selection of growers who will participate in the experiment. After completion of the determination of grower data requirements and data forms, discussions would be held with the growers to make a final determination of which will participate in the experiment. During these discussions, the availability of an historical data base will be ascertained for possible inclusion as part of the control group. The specific procedures for data gathering will be developed with the assistance of the USDA and Citrus Growers Association.

Preliminary cost and loss determination methodologies will be developed and detailed citrus grower and National Weather Service data requirements determined. These data requirements would be reviewed with the USDA, Citrus Growers Association and National Weather Service. The result would be the determination of the specific data needs matched with the availability of data from the growers and the NWS. Finally, data forms will be developed which will place major emphasis upon minimizing the grower time requirements. The data forms

will be of two types, one to gather the data which may be considered as invariant during the frost season and one to gather data on the daily events, decisions and actions (see Section 4.4.1). Sources will be developed for obtaining "global" data such as citrus crop spot and futures prices, fuel prices, etc.

The preliminary cost and loss methodologies will be developed in detail incorporating information provided by the USDA, NWS and Citrus Growers Association. The cost and loss methodologies will result in the determination of the average cost and loss per frost event. The methodologies will be expanded to yield annual cost and loss, for both the control and test groups, in terms of number of frost days. The difference between these costs and losses is the annual benefit of the improved forecast to the citrus growers comprising the sample. Procedures will be developed for extrapolating these results across the Florida citrus industry, taking into account grower location, frost protection practices, frost occurrences, etc.

This task will also be concerned with the development of the methodology for estimating grove temperature (which would have occurred if protective action were not taken) in terms of control thermometers which are not co-located with the grove. The grove temperature which would have occurred is necessary in order to establish a measure of frost severity.

Last, but not least, methods will be developed for the efficient manipulation of the large quantities of data which will be collected from both the citrus growers and the National Weather Service.

4.4.2.2 Data Collection

The data collection task is concerned with gathering the necessary data, both current and historical, from citrus growers and the National Weather Service. Based upon the procedures which are developed for data collection and the data collection forms, participating growers will be instructed in data collection methods and requirements. Continued coordination will be maintained with the USDA and growers to assure the necessary data flow. The primary interface with the growers during the data collection will be the USDA*. It is extremely important that the growers maintain careful and complete daily records as per the provided data forms. It is anticipated that a significant effort will have to be devoted to grower coordination to assure the necessary flow of accurate data.

An analysis will be performed to determine the availability of pertinent historical grower data for incorporation into the control group data base. Appropriate data will be collected. Based upon the data sources previously established, data will be collected on citrus spot and future prices, fuel prices and other necessary data found to be common to all growers.

Continued coordination will be maintained with the National Weather Service to assure the necessary data flow. If it is found that grower historical data can be used as part of the control group, then historical temperature forecast data and historical recorded temperatures at NWS control thermometers will be collected. In any event, during the 1976-77 and following frost seasons, daily weather

*As per private communication with Dr. John Jackson, USDA County Extension Agent, Multi-County, Florida.

forecasts and daily recorded control thermometer temperatures will be obtained from the National Weather Service.

4.4.2.3 Data Reduction

The data reduction is concerned with the review of the collected data and transformation of the data into suitable form for entry into a general data base. As data is received, it will be reviewed for correctness and consistency. If problems are encountered, data forms and data collection procedures will be reviewed and altered accordingly.

Procedures will be developed which will "flag" possible inconsistencies in data. For example, data will be compared between similar groves and data which seem questionable will be noted. The growers will then be contacted, through the USDA, to determine if indeed an error was made or data requirements were misinterpreted. This is particularly important during the early stages of data collection where it is anticipated that misunderstandings will exist and need rapid clarification.

The data reduction task is also concerned with the determination of the accuracy improvement of temperature and frost forecasting which may result from the utilization of SMS data in combination with improved temperature forecasting models. This will be accomplished by utilizing the combination of NWS forecasts, NWS control thermometer and other data, and grove observations which are to be collected as part of the economic experiment.

4.4.2.4 Economic Analysis

The economic analysis is concerned with the determination of annual saving which occurs as a result of improved temperature forecasts

and based upon the data obtained from the citrus growers and the National Weather Service. In order to establish the level of frost severity, an important input for event segmentation, control thermometer temperature from NWS or grower control thermometers will be used to compute grove temperature. Cost and loss per event will then be established and segmented accordingly. The results of these computations will be reviewed with the growers, particularly during the early phases of data collection, in order to determine errors in methodology and/or input data and to maintain quality control throughout the data collection periods. Daily costs and losses will be established for each grove and classified by event type (see Section 4.3.2), citrus grower type and frost severity. At the end of each frost season (including historical seasons), average costs and losses will be determined so that annual costs and losses can be established for the control and test groups. The results of the control and test groups will be compared and the annual demonstrated savings (both dollar savings and fuel savings) will be established. These savings, based upon the sample population, will be extrapolated to total Florida citrus industry annual savings, taking into account grower geographic locations, geographic temperature patterns, grower crop protection capabilities, crop type, etc. The net result will be the establishment of demonstrated benefits and extrapolated (from the measured benefits) benefits which are the direct result of improved frost protection decisions made possible by the improved temperature forecasting capability.

4.4.2.5 Econometric Modeling

This task is concerned with assessing the economic benefits which can be achieved as a result of improved knowledge of recent temperature distributions throughout the State of Florida. It is anticipated that improved knowledge of recent potential crop damage throughout the state can lead to improved marketing decisions (i.e., decisions pertaining to harvesting for fruit or concentrate, pricing decisions, current frost protection decisions, etc.). The economic experiment described in the previous pages is not designed to measure the benefits which may result from improved marketing decisions. The reason for this is primarily one of sample size. To measure the marketing decision benefits, it appears necessary to consider establishing a data base over a relatively large number of years--this has been assumed to be impractical and thus the omission from the experiment. It is anticipated, however, that the economic benefits from improved marketing decisions may be relatively large--perhaps much larger than the direct savings from improved frost protection decisions. Therefore, even though the benefits are not measurable as part of the economic experiment, it is recommended that econometric models be developed during the course of the experiment so that the full benefits due to the use of SMS data and the improved temperature forecasting models can be evaluated.

Improved marketing decisions by citrus inventory holders can result from improved yield forecasts as provided by the SMS-generated statewide temperature maps. If, for example, a large part of Polk county experienced 26°F for four hours, a fairly good guess could be made as to the reduction in statewide fresh fruit yield

caused by the frost. Improved yield forecasts can benefit both the consumer and the inventory holder as the increased efficiency of the market allows better temporal distribution of the citrus. Both consumer and inventory holder, for example, would suffer if an underforecast of the actual yield produced abnormally high prices for citrus in one month and then abnormally low prices for citrus in the next month as the true size of harvest became known. In short, violent price swings produce a net disbenefit for society.

This concept can best be seen within the simplified framework of the Hayami-Peterson two period model. Y. Hayami and W. Peterson [15] considered the question of how much to invest in reducing the forecast error in yield estimates, using a two-period model in which the amount held in inventory in the first period is a function of the amount forecast to be produced in the same period. By definition of a two-period model, any produce held in the second period is sold or liquidated by the end of the second period. Therefore the amount held during the second period is a function of only the amount sold in the first period. The social value of the resulting sequence is measured by a unique area found under the product's demand curve for the two periods. Forecast accuracy is valued for its effect on the expectation of this welfare sum.

The inventory adjustment model applies to situations where production cannot be altered significantly in response to output predictions, but where there is an opportunity for inventory holders to adjust stocks. A good example occurs in agriculture in the case of food and feed grains. Once the crops are planted, it is usually not

profitable for producers to significantly expand or contract the output. On the other hand, it is relatively easy and inexpensive to store these commodities. In this case, any market supply adjustment is possible mainly through adjustment in inventories.

For products of this type, the social cost of misreporting of future production, through such errors as acreage or yield estimates, arises because of distortions in the optimum consumption patterns of the products. Because products of this type are produced during a relatively short period of time within the year, their consumption patterns depend very much on the inventory policy of marketing firms. For example, the expectation of an abnormally small crop in the forthcoming production period and of a higher price can be expected to result in a decreased rate of inventory depletion during the remainder of the current period. This in turn results in increased prices and a decreased rate of consumption during the current period.

This situation is illustrated in Figure 4.17. It is assumed in this case that production response to a price change can be approximated as being perfectly inelastic during the production period, as denoted by the supply curve SS. The market demand schedule for the commodity is denoted by DD.

Suppose the statistical reporting agency estimates the current period production as OQ' as opposed to the actual or "true" production OQ. Inventory holders, in forming price expectations for the coming period, expect the average price to equal OP'. In other words, they would expect the future price to be higher by PP' (or BG) than would be the case had no error been involved in the production estimate. Consequently inventory holders find it profitable to decrease

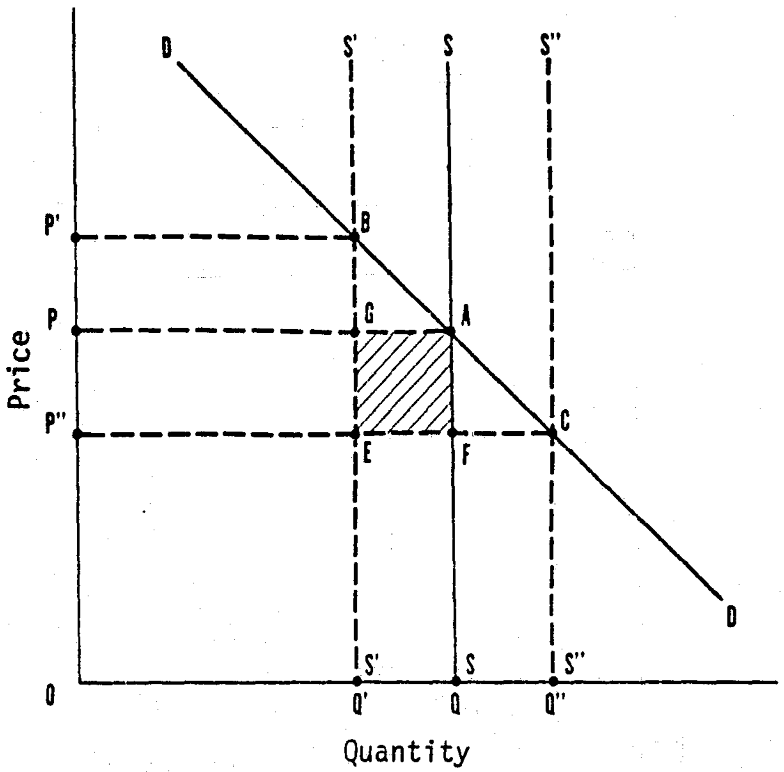

Figure 4.17 Inventory Adjustment Model

their rate of inventory depletion for the remainder of the year, until current price has risen by PP'. Consumption then would contract to OQ', or by the amount Q'Q. In turn, the inventory carry-over into the next production period would be increased by the same amount, Q'Q. As a consequence, the reduction in consumption during the current period would reduce consumer welfare by the area ABQ'Q.

Because of the abnormally large carry-over into the next period, it is assumed that the next period supply would increase by the amount Q'Q which is equal to QQ" in Figure 4.17. Hence the total quantity placed on the market during the next period would be the "true" production OQ plus the increased carry-over QQ". The result would be a decrease in the average price down to OP" as opposed to

price OP which would have prevailed had there been no reporting errors. The decrease in price, however, results in an increase in consumption during the next period by the amount QQ". Thus total consumer welfare is increased during the next period by ACQ"Q. The overall result of reporting errors that gave rise to the decline in current consumption and the increase in future consumption is a net loss in consumer welfare equal to rectangle AGEF (area ABQ'Q minus area ACQ"Q), the shaded area in Figure 4.17, assuming that the demand curve is linear. The same amount of net welfare loss would have resulted from an erroneous overestimate of production, that is, if OQ" would have been predicted instead of OQ'.

It is this concept which may be applied to estimate the economic benefits of improved knowledge of statewide temperature patterns and their impact on yield.

4.4.2.6 Reporting

Both oral briefings and written reports will be provided. Oral briefings will be given as required, however, it is anticipated that briefings will be given prior to the start of the 1976-77 frost season and will detail the experiment design and, in particular, the plans for control group data collection. Other briefings will be given at the completion of the data and economic analysis tasks associated with each frost season. Monthly activity reports will be provided. A detailed annual report will be provided at the end of each year. The annual report will describe in detail the methodology, the data collection techniques, the collected data (growers, National Weather Service and others) and established results.

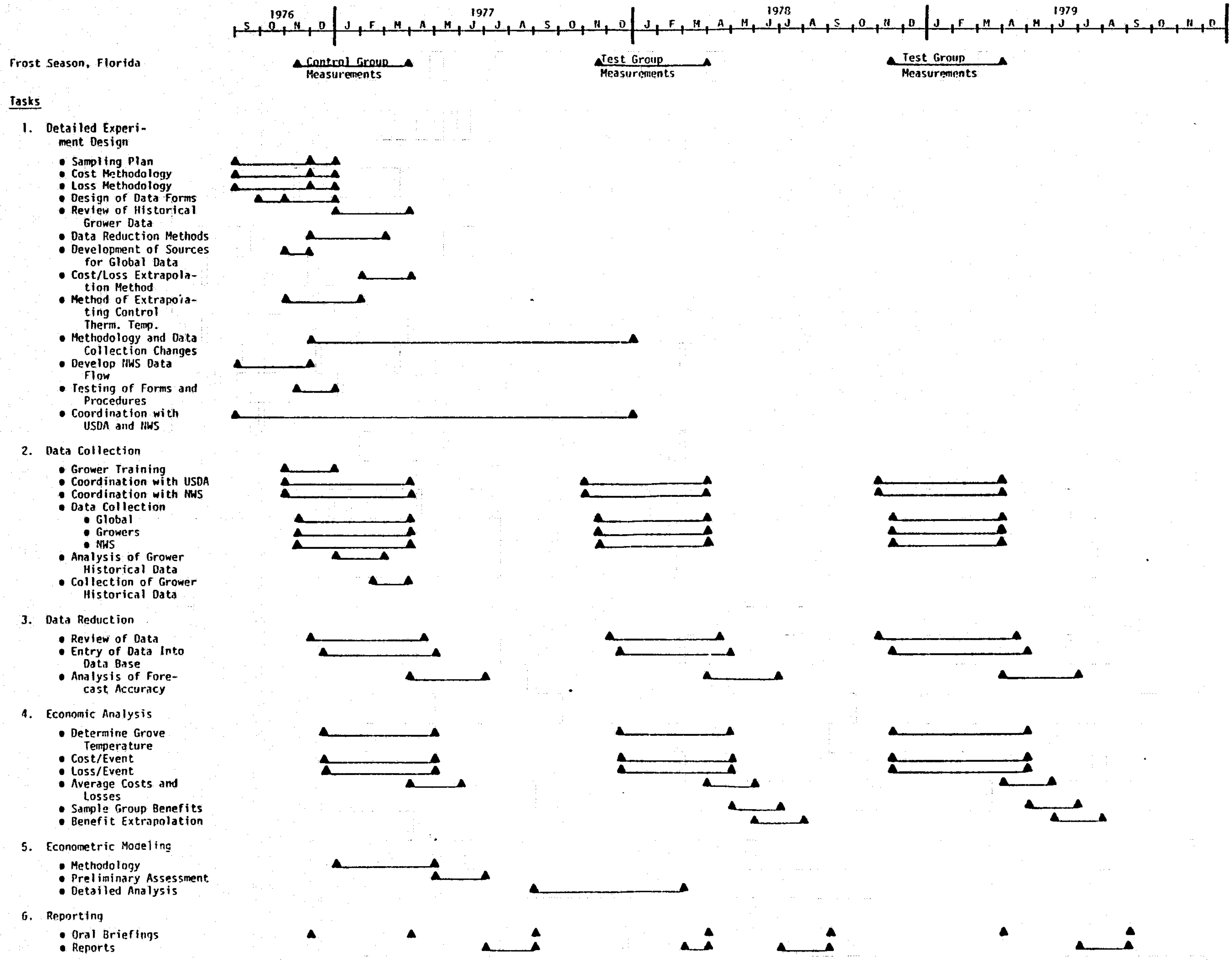

Figure 4.18 Schedule for Florida Citrus Crop ASVT (Economic Experiment)

4.4.3 Schedule

The schedule for the Florida citrus crop ASVT (Economic Experiment) is detailed in Figure 4.18. The schedule encompasses a time period from September 1, 1976 through August 31, 1979. This enables data to be collected through three frost seasons, the first being for control group measurements and the latter two for test group measurements. The consideration of two test group frost seasons allows for the highly likely possibility that it will not be possible to collect reliable data during the 1977-78 frost season because the citrus growers decision processes will be evolving to adjust to the improved temperature and frost forecasts.

The experiment schedule must be built around the Florida frost season which may start as early as mid-November and end as late as the end of March. Since the overall ASVT schedule calls for the operational use of the SMS data in temperature forecasting to commence during the latter part of 1977, it will be possible to measure control group costs and losses during the 1976-77 frost season. This dictates the very rapid development of the detailed experiment plan, in particular, the sampling plan, the cost and loss methodologies and the data forms. These must be completed no later than the early portion of the 1976-77 frost season in order to ensure the collection of the control group data.

The schedule in Figure 4.18 delineates the various tasks shown in the functional flow of the experiment illustrated in Figure 4.16. In general, the detailed experiment design will take place during the latter part of 1976 and early part of 1977. Data collection will take

place during November through March of 1976-77, 1977-78 and 1978-79. Data reduction will cover approximately the same time periods. The economic analysis of the daily data will also encompass approximately the same time periods with the determination of average costs and losses and benefits associated with the sample population, and the extrapolation to all applicable growers occurring May, June and July of each year.

The econometric modeling task is divided into two phases. The first phase consists of the development of the methodology to be used to evaluate the economic benefits of improved citrus growers marketing decisions made possible by current statewide temperature data. This will thence be followed by a preliminary quantitative assessment of the benefits in order to assess the desirability of performing the second phase, the detailed analysis of the benefits.

Finally, the schedule indicates the timing of oral briefings and annual reports. Other briefings will be provided as required, possibly to the citrus growers and their associations, in order to provide a feed-back mechanism to those who have had the patience and perseverence to supply the necessary data.

4.4.4 Management

The participants in the Florida Citrus Crop ASVT (Economic Experiment) are indicated in Figure 4.19. The participants are the University of Florida, National Weather Service, NASA, Citrus Growers Association, citrus growers, USDA (County Extension Agents) and ECON, Inc. The roles of the participants are also indicated in Figure 4.19 and summarized below.

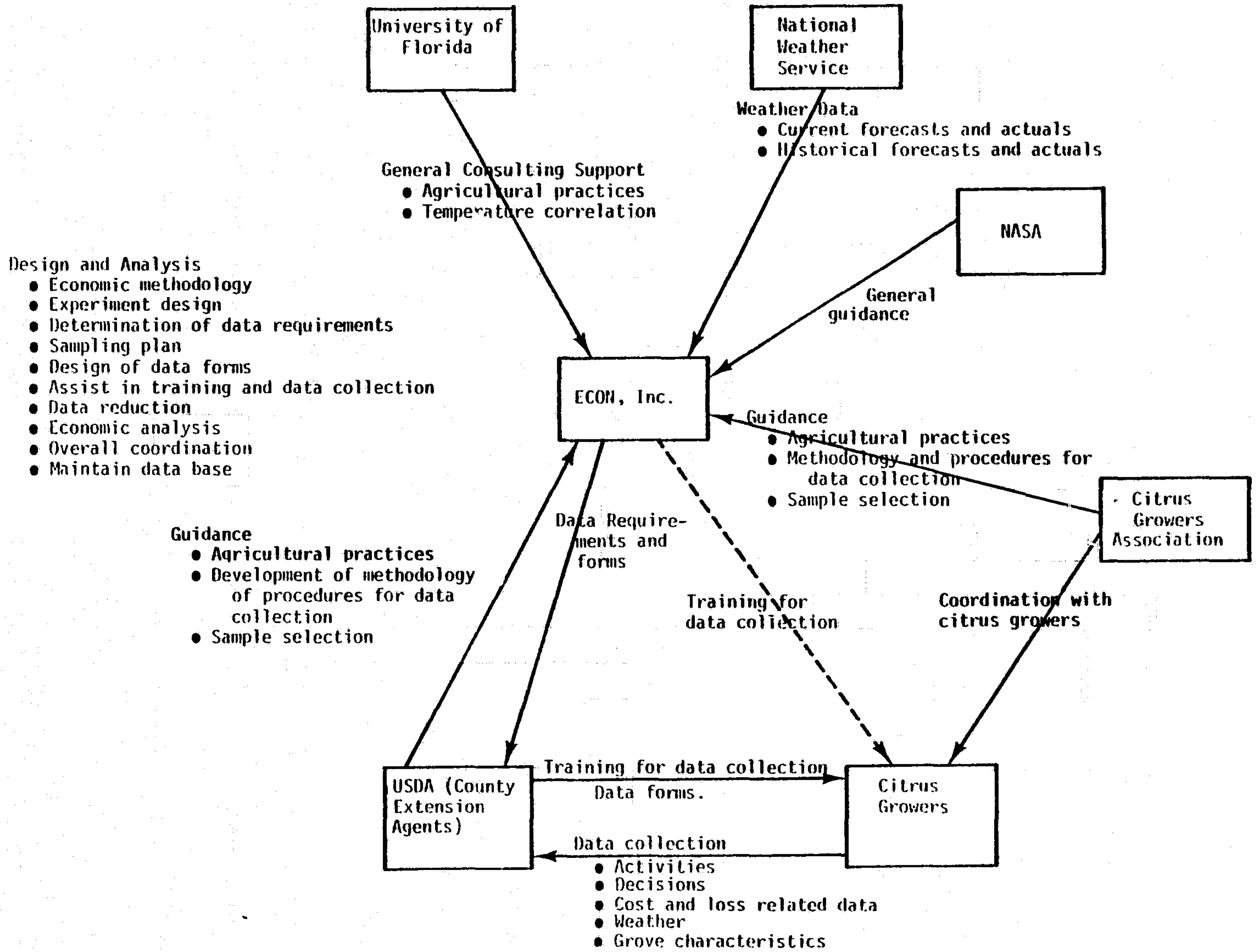

Figure 4.19 General Areas of Activity for Economic Benefit Experiment

ECON, Inc.: ECON will design the experiment, determine the data requirements and participate in the data collection and will perform the analysis of the data which will result in the benefits of the improved forecasts to the sample population and extrapolated to the Florida citrus industry. ECON will also assist, in cooperation with the USDA, with the general training of the citrus growers with respect to data collection and ECON will develop and provide the data collection forms. ECON will also, along with the USDA, continue to coordinate with the citrus growers and the NWS in order to assure an accurate and timely flow of data.

University of Florida: The University of Florida will provide general consulting support to ECON particularly in the areas of citrus growers agricultural practices and techniques for estimating grove temperature in terms of NWS or citrus grower control thermometers which are displaced from the groves whose temperatures are to be estimated. The University, as part of the overall ASVT, will provide to the NWS the mathematical models and computer programs which will provide improved temperature forecasts based upon SMS data.

National Weather Service: The National Weather Service will provide weather forecasts to the citrus growers in Florida. These forecasts, during the 1976-77 frost season, will not make use of the SMS temperature data. During the following frost seasons, the NWS forecast will incorporate the SMS temperature data. The NWS will furnish current forecast data and actual weather occurrence data (primarily control thermometer measurements) to ECON. Also, as found to be necessary by the

availability of grower historical data, the NWS will also furnish historical forecast data and actual weather occurrence data to ECON.

NASA: NASA will provide general guidance to the participants in the experiment. In particular, NASA will direct the overall efforts of ECON and the University of Florida.

Citrus Growers Association (Florida Citrus Mutual): The Citrus Growers Association will provide general guidance to ECON in the areas of citrus growers agricultural practices, methods and procedures for data collection and sample selection. The Citrus Growers Association will also provide general coordination with, and education of, the citrus growers.

Citrus Growers: The citrus growers will provide data to ECON (via the USDA) pertaining to their activities, decisions and costs and losses associated with citrus crop frost protection. This data will be provided on a daily basis. Weather occurrence data will also be provided on a daily basis. The growers will also provide, on a seasonal basis, general grove data.

USDA (County Extension Agents): The USDA County Extension Agents, because of their detailed experience with and knowledge of the citrus growers and their operations, will be the direct interface with the citrus growers. Therefore, the USDA will participate in the training of the citrus growers for data collection and will provide the data forms to, and collect the data from, the citrus growers. The USDA will provide general guidance to ECON in the areas of citrus grower agricultural practices, development of methods and procedures for data collection, and provide detailed assistance in the final formulation of the sampling plan.

Because of the relatively large number of participants in the experiment and the need for continued coordination and review, it is recommended that a Coordination Working Group be established with each of the above organizations providing one member of the Working Group. It is recommended that the NASA representative serve as Chairman of the Working Group. The function of the Working Group would be to provide responsible points of contact within each of the organizations who, in turn, would see that their organizations perform and cooperate as required. The Working Group would provide the mechanism for ironing-out difficulties or coordinations. The frequency of meeting of the Working Group should vary depending upon the criticality of the efforts underway. For example, during the first several months it might be desirable to meet monthly, whereas during the latter part of the data collection phases and economic analysis phases, meetings might take place at three-month intervals. It is imperative, because the weather will not wait for men, that a smoothly functioning overall organization be established of highly dedicated people to insure the timely collection of data and the orderly flow of data.

4.4.5 Manpower Requirements and Budgetary Estimates

The anticipated manpower requirements are illustrated in Figure 4.20 and manpower requirements and budgetary estimates are summarized in Table 4.19 for a three (3) year experiment which assumes that the 1976-77 frost season will be used to collect control group data and the following frost seasons will be used to collect test group data. The manpower estimates and budgetary estimates <u>do not include</u>

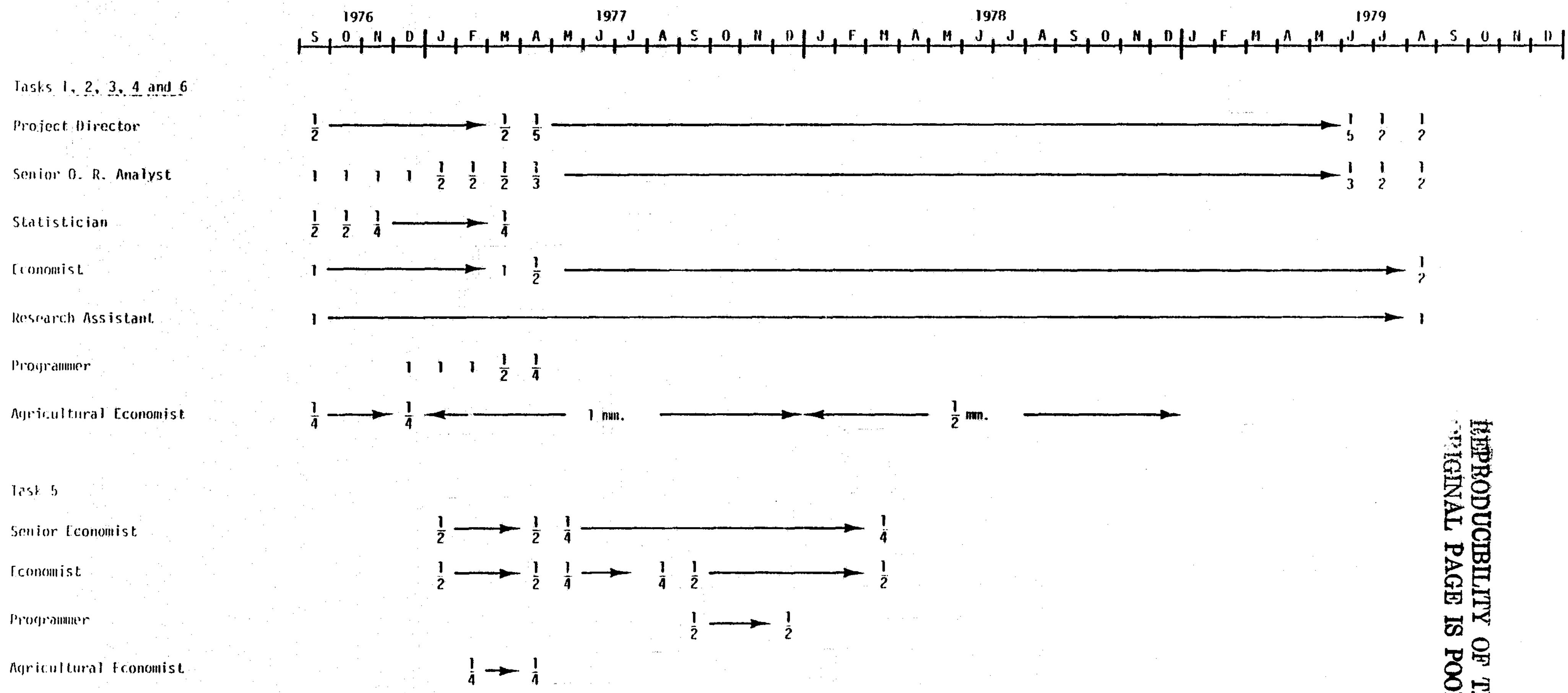

Figure 4.20 Manpower Projections for Florida Citrus Crop ASVT (Economic Experiment) (man months/month)

Table 4.19 Manpower Requirements (man-months/year) and Budgetary Estimates (K$/year)

Tasks 1, 2, 3, 4 and 6	Sept.'76-Aug.'77	Sept.'77-Aug.'78	Sept.'78-Aug.'79
Manpower			
Project Director	4 - 5	2 - 3	2 - 3
Senior O.R. Analyst	6 - 8	3 - 4	3.5 - 4.5
Statistician	1.5 - 2.5	-	-
Economist	8 - 10	6	6
Research Assistant	12	12	12
Programmer	3 - 4	-	-
Agriculture Economist	1 - 2	.5	-
TOTAL (mm/year)	35.5 - 43.5	23.5 - 25.5	23.5 - 25.5
Budget Estimates (K$/year)	175 - 215	115 - 125	115 - 125
Task 5			
Manpower			
Senior Economist	3	1.5 - 2	-
Economist	3	3 - 4	-
Programmer	-	2	-
Agriculture Economist	.5 - 1	-	-
TOTAL (mm/year)	6.5 - 7	6.5 - 8	-
Budget Estimates (K$/year)	40 - 43	36 - 45	-

time which will be spent and costs which will be incurred by the University of Florida, National Weather Service, Citrus Growers Association and citrus growers in assisting with the performance of the economic experiment portion of the Florida Citrus Industry ASVT.

The manpower and budgetary estimates are provided separately for the experiment tasks and the econometric task (Task 5). Referring to Tasks 1, 2, 3, 4 and 6, the role of the manpower is as follows:

- Project Director - Serve as the primary source of coordination with other participants in the experiment, direct the efforts of the technical staff involved in the design and conduct of the experiment, and participate in the design of the experiment.
- Senior O.R. Analyst - Responsible for the detailed experiment design and day-to-day performance of the experiment; serve as the senior technical man on the project.
- Statistician - Participate in the formulation of the sampling plan and review of initial data.
- Economist - Participate in the development of the economic analysis methodologies and assist with data collection, data reduction and economic analysis.
- Research Assistant - Participate in the overall experiment design and assist with data collection, data reduction and economic analysis.
- Programmer - Responsible for the implementation of computer programs associated with the data reduction and economic analysis.
- Agricultural Economist - Provide general guidance pertaining to agriculture practices and economics.

With respect to Task 5, Econometric Modeling, the role of the indicated manpower is as follows:

- Senior Economist - Responsible for the formulation of the econometric models of the benefits which may result from improved knowledge of temperature distributions associated with marketing decisions.

- Economist - Participate in the development of the econometric models under the direct supervision of the Senior Economist. Perform the economic benefit assessments using the developed models.
- Programmer - Responsible for the implementation of the econometric models.
- Agriculture Economist - Provide general guidance pertaining to farming practices and citrus grower decision logic and market consequences.

The budget required to perform the tasks directly associated with the economic experiment is \$175,000-\$215,000; \$115,000-\$125,000; and \$115,000-\$125,000 for the three years, respectively. The budget required to perform the econometric modeling task is \$40,000-\$43,000 for the first year and \$36,000-\$45,000 for the second year. It should be noted that if the results(Task 5) of the preliminary benefit assessment do not yield significant benefits, the second year's effort may be foregone.